UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 275
Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER April 7, 1916

FOREST PATHOLOGY IN FOREST REGULATION

By

E. P. MEINECKE, Forest Pathologist, Office of Investigations in Forest Pathology

CONTENTS

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CONTENTS.

INTRODUCTION.

At the time of the creation of the national forests in the United States the Government very suddenly found itself confronted with the problem of organizing an enormous acreage of practically virgin timber. It was natural that American forestry turned to the experience of the Old World for guidance in this huge task; it was quite as natural that the present state of European forestry should have served as the ideal to be reached in the shortest time possible. In organizing the administrative machinery, European precedent could be followed more or less closely, but not so in almost all other phases of forestry. Except for certain economic factors and the development of modern machinery, conditions influencing the lumber industry in the United States are very dissimilar to those in the typical forest countries of central Europe. Our virgin forests them-

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NOTE.—This bulletin discusses the bearing of modern forest pathology on forest regulation.

selves, and consequently the timber for sale, are more or less in the condition of European forests of several hundred years ago. The administration found itself then in the position of a man forced to take over not only an obsolete factory producing at random articles of daily necessity in enormous quantities without having any control whatever over the quality turned out, but also a huge stock of products of all kinds and all values. Modern sales methods alone can not make the product any better, and the sudden adoption of modern methods of efficiency in the manufacturing end of the business would soon disorganize the entire factory.

It is clear that in the most important branch of forestry, silviculture, the blind adoption of European methods must encounter serious difficulties. Perhaps we are too prone to look upon European forestry as a science worked out in all its details, the results of which are universally accepted as definitely settled. Critical perusal of modern European forestry literature shows an entirely different state of affairs. Even in Germany many of the fundamental problems of forest organization are steadily discussed and are far from being considered as settled. Furthermore, what Gaskill[1] said 11 years ago is true to-day, namely, that "European foresters have not developed a true system or science of silviculture capable of being applied to virgin conditions or to all conditions."

The lessons taught us by earlier forest history in Europe, the adaptation rather than adoption of European principles to American conditions, and the development of new principles to suit our own special needs are therefore the means by which forestry in the United States will finally solve the silvicultural problems before it at the present day.

REGULATION OF YIELD.

WORKING PLANS.

One fundamental problem has occupied the administration of the national forests ever since their creation, that of working plans as the expression of forest organization leading to sustained yield.

Any speculation with regard to the adoption of a system of regulation must necessarily refer to the normal stand, whether this is clearly understood and stated or not. Now, there is no such thing as the 100 per cent normal stand. Consciously or subconsciously the normal stand is taken as the ideal, and from this allowances are made according to the degree in which the stand deviates from the normal. It is a remarkable fact that even in European forestry no working system has developed of expressing with accuracy the value of allowances to be made. This is partly due to the fact that the managed European forests are relatively closer to the normal. Frequent thinnings and improvement fellings eliminate most of the undesirable indi-

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[1] Gaskill, Alfred. Silviculture applied to virgin forest conditions. *In* Proc. Soc. Amer. Forest., v. 1, no. 2, pp. 62-69, 1905. (See p. 67.)

viduals from the stand, which is kept as fully stocked as possible. The problem is further simplified by the prevalence of pure stands or of stands composed of two, rarely more, well-matched species. The management of even-aged stands or stands of all ages also permits a relatively close approximation to the normal.

All these factors are comparatively rare in our practically virgin forests, which are about as far from the normal as possible. As forests they are with few exceptions rather 100 per cent abnormal, and this applies equally well to all unmanaged practically and genuinely virgin forests of the world. The farther the forests are removed from the normal the less can European results from relatively normal stands be applied, and particularly if the abnormality is complicated by the presence of a greater number of commercial species on the same stand, as is so often the case in our forests. It is not to be expected that at the very beginning of its career the Forest Service should have possessed all the facts upon which to base a rational system of sustained yield. Intensive work of decades is necessary to secure even the very foundations.

It is clear that this lack of fundamental facts must be reflected in any attempt to establish some system of sustained yield and, therefore, in any policy of regulation of cut. While Kirkland [1] emphatically demands a policy of cutting national-forest timber on the Pacific coast on the basis of a sustained annual yield, Greeley,[2] on the other hand, points to the difficulties confronting the establishment of a sustained annual yield in the forests of the United States. In his opinion even, "modern conditions governing the distribution and sale of lumber make the sustained yield from the standpoint of a permanent supply for consumers of wood very much of a fiction." We have at the present time no more authoritative statement concerning the policy of the administration of the national forests.

With regard to the regulation of sustained yield, Chapman [3] arrives at a similar result in discussing the regulation of cut on national forests.

> Until recently the annual cut permitted upon national forests has been determined by Von Mantel's method, based solely on the present nature of the merchantable stand and a somewhat arbitrary rotation. A few attempts have been made lately to base the cut upon the increment of the forest by use of the Austrian formula. At the same time there has come a general awakening to the fact that our knowledge of the actual increment of virgin forests is conspicuously lacking. Without this knowledge systematic regulation of yield must remain on crude and wholly unsatisfactory foundations. The question can not be dodged by quoting the generality that in virgin forests growth equals decay.

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[1] Kirkland, B. P. The need of a vigorous policy of encouraging cutting on the national forests of the Pacific coast. *In* Forestry Quart., v. 9, no. 3, pp. 375–390, 1911.

[2] Greeley, W. B. National forest sales on the Pacific coast. *In* Proc. Soc. Amer. Forest., v. 7, no. 1, pp. 42–50, 1912.

[3] Chapman, H. H. Coordination of growth studies, reconnaissance and regulation of yield on national forests. *In* Proc. Soc. Amer. Forest., v. 8, no. 3, pp. 317–326, 1913.

This "generality," in which almost every word is open to criticism, seems to have become one of the stand-bys of American forestry. It finds its chief support in the assumption that our forests to-day, having been untouched by man and exposed to the same factors of their surroundings since times immemorial, must represent more or less exactly the same character they had 100 or 1,000 years ago. But we have practically no genuinely virgin forests; in the great majority of commercial accessible stands—and here we are interested only in these—man has for centuries practiced some kind of primitive forestry by setting fires. This "Piute forestry" has changed the aspect of many stands so completely that the term "virgin forests" is far from being correctly applied. At best, can one speak of scattered virgin stands here and there. Even in the latter the assumption that the present stand has more or less the same character as 100 to 1,000 years ago reposes upon another assumption, namely, that here the ecological formation has reached the final stage of development and has come to stay. Of the remaining part of the cited rule of thumb all factors are more or less unknown.

Our knowledge of increment is, according to Chapman, "conspicuously lacking."[1] We know just as little about actual extent and progress of decay in virgin forests, so that the "generality" is reduced to an equation in which all factors are unknown. Besides, the term "decay" leaves out all losses from the decrease in number of trees steadily going on in the forest, as in every community of living beings. Prompted, perhaps, by a subconscious realization of this fact, the term "decay" in the equation is sometimes supplanted by "deterioration." This makes matters even worse. Deterioration in this connection often means the visible loss irrespective of cause. It is primarily a numerical consideration. A number of trees containing certain amounts of timber annually drop out through various causes, and this loss is then said to offset the annual increment. Secondarily, it might include loss from decay. In forest regulation it is not the number of trees and the volume of timber they produce per acre that count, but the volume of sound, merchantable timber that we can expect to raise; and the only factor in the equation of any value would be, therefore, not decay only and deterioration or numerical loss of individual trees but "total loss." The components of this total-loss factor are known. They include the dropping out of individual trees by death from suppression or "old age," fire, snowbreak, lightning, windfall, insects, diseases of vital parts of the tree, and finally loss through decay. What we do not know are the respective values to substitute for these components in the actual figuring of total loss.

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[1] More recently Barrington Moore has published a valuable study—Yield in uneven-aged stands—in Proc. Soc. Amer. Forest., v. 9, no. 2, pp. 216–228, 1914.

The same laxity noted in the use of the terms "decay" and "deterioration" is commonly found in the use of the term "decadence," as applied to a stand or a given species, which is often understood to include individual decadence from old age; that is, arrested or minimized growth, liability to attack from fungi and insects, and finally decay. The fact that a given species is unusually liable to heart rot does not make it decadent. Many of our most thrifty and aggressive species are particularly subject to heart rot. It is also doubtful whether this hypothetical knowledge, if ever attained, of the total rate of total loss in "virgin" forests, as compared with the equally hypothetical rate of increment of the forests as a whole, would help us to any extent. The vastness of our forests in area creates a tendency either to think in broadest terms and to overlook the fact that a forest is an artificial unit made up of natural units, the stands with all their immense variety of character, or, on the other side, to take a familiar unit and to transfer its characteristics to the whole. The latter mistake is more easily remedied than the first. As a science, forestry must be founded upon inductive methods. Intensive study of detail alone can form a solid basis for the formulation of principles.

What is needed is exact studies of all components of the total-loss factor per species before we attempt to fix the total-loss factor for the stand.

Such detailed studies will be easiest in all-aged pure stands of a thrifty species little liable to decay. Unfortunately the vast majority of stands on national forests in the West are composed of two to five or more species of very different characters. It may be that the total annual loss equals the annual increment in some of the medium long-lived species of the pine group least liable to decay. It can not be true for the extraordinarily long-lived redwood and big tree, with their unusual resistance to decay, insects, and storms. It is equally untrue for all shorter lived species much exposed to decay and other influences that make for loss. *Libocedrus decurrens*, for example, although most aggressive and thrifty, is from an early age on liable in an uncommon degree to the attacks of *Polyporus amarus*, which renders as much as 70 or 80 per cent and even higher percentages of the stand completely unmerchantable. Merchantable incense cedar is of high value; so much the greater, then, is the total-loss factor. The same is, mutatis mutandis, true for white fir and a number of other species. For all these the increment is not only offset but far exceeded by the decay of the valuable heartwood; the total annual loss is far greater than the annual increment, although numerically the loss may not be apparent.

The gain through increment, we must remember, consists of sapwood of little value; the loss by decay, on the other side, affects the valuable heartwood. Neither is there any constant accumulation of gain; after some years the sapwood is turned into heartwood and as such becomes liable to decay. In other words, in trees of this group infected with heartwood-destroying fungi, the value of newly formed wood is small; when it becomes valuable by transformation into heartwood it becomes subject to decay—that is, loss. This loss from decay is by its very nature as a heart rot confined to those individuals in which heart-rot formation has taken place. All trees below the age of heartwood formation do not enter into consideration. In speaking of a given stand the representation by ages must be of prime importance. In all considerations of regulation it is necessary, therefore, to make a clear distinction between forests and stands, between many-aged and even-aged stands, between mixed and pure stands, with particular emphasis on the composition of the stand as to species. All generalization is not only useless but misleading.

But in full realization of the almost complete lack of fundamental knowledge, American forestry is confronted with the urgent necessity of adopting, even temporarily, some kind of a system of regulation of yield. Whatever this system may be, its tentative, temporary, and local character can not be overemphasized.

Various attempts at adopting local temporary systems have found an expression in the shape of working plans. Inseparable from the problem of working plans is the choice of a rational rotation and cutting cycle.

ROTATION.

The gleanings in American literature treating on the choice of rotation from a general point of view are rather meager, outside of a few well-known handbooks, such as those by Recknagel,[1] by Fernow,[2] and by Roth,[3] particularly in so far as the practical application to our virgin forests is concerned. Recknagel [4] excludes financial rotation from North American forests with the following words:

> Since this method of calculating the rotation [financial rotation or that of highest soil rent] is suitable only to very intensive conditions, it would serve no useful purpose to elaborate it at this point.

On the other hand, the strong influence of European forestry is clearly felt in the ever-recurring advice to adopt some kind of a financial rotation in the national forests of the United States. Kirkland [5] is of the opinion that—

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[1] Recknagel, A. B. The Theory and Practice of Working Plans (Forest Organization), 235 pp. New York, 1913.

[2] Fernow, B. E. Economics of Forestry, 520 pp. New York, 1902.

[3] Roth, Filibert. Forest Regulation, or the Preparation and Development of Forest Working Plans, 218 pp., illus. (maps). Ann Arbor, Mich., 1914. (*His* Michigan Manual of Forestry, v. 1.)

[4] Recknagel, A. B. Op. cit., p. 39.

[5] Kirkland, B. P. Working plans for national forests of the Pacific Northwest. *In* Proc. Soc. Amer. Forest., v. 6, no. 1, pp. 16-37, 1911. (See p. 21.)

A rotation based on the financial rotation, possibly modified somewhat towards the rotation of the highest income, is no less adapted to Government forestry than to private forestry.

Greenamyre[1] advocates a financial rotation in the composite type of the Apache National Forest, the "rotation of greatest volume production being out of question." In his specific recommendations for western yellow pine, Douglas fir, and blue spruce, however, rotation of greatest volume plays a far greater rôle than financial rotation. Such important factors in financial rotation as soil capital, quality increment, and rent are neglected or only hinted at. Value increment and depreciation enter into his calculations in a general way only, evidently from a lack of exact figures.

Barrington Moore[2] expresses himself strongly against the adoption of a financial rotation.

It would be out of place in this paper to enter into a discussion of the possibility at the present time of fixing a rotation of greatest income or a financial rotation more deeply than to point to the immense difficulties encountered as soon as we try to substitute actual values for the factors entering into their computation derived from experience in our own country. We lack at the present time the very fundamentals on which to base the determination of highest forest rent or highest soil rent.

The Forest Service has, in full realization of the uncertainty of almost all factors which would or should enter into a financial rotation formula, adopted, for the present at least, a tentative silvicultural rotation of maximum-volume production.

The factors entering into the determination of silvicultural rotation or of greatest volume being more easily accessible, it is quite natural that American forestry should show a tendency toward its application, as shown in a number of published and unpublished working plans.

Attempts at fixing some kind of a rotation age are found in several publications. Woolsey[3] tentatively proposes a rotation of 200 years for yellow pine without giving a basis for the choice of any particular system of rotation.

Barrington Moore[4] says that on the Plumas National Forest "the rotation should theoretically be that of maximum-volume production. The use of a financial rotation by the Government, in a region

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[1] Greenamyre, H. H. The composite type on the Apache National Forest. U. S. Dept. Agr., Forest Serv. Bul. 125, 32 pp., 4 figs., 1913. (See p. 30.)

[2] Moore, Barrington. The essentials in working plans for national forests. *In* Proc. Soc. Amer. Forest., v. 6, no. 2, pp. 117-128, 1911. (See p. 126.)

[3] Woolsey, T. S. Western yellow pine in Arizona and New Mexico. U. S. Dept. Agr., Forest Serv. Bul. 101, 64 pp., 11 figs., 4 pls., 1911. (See p. 51.)

[4] Moore, Barrington. Chapman's method of studying yield, p. 93, 1913. To accompany forest plan, Plumas National Forest, district 5. Appendix (continued), Silviculture. (Unpublished. Furnished by courtesy of the U. S. Forest Service.)

capable of producing large saw timber, can not be justified. * * * It would probably be better to fix the rotation at the period during which the *rate* of volume production is greatest or shortly after it, provided this is long enough to give the most valuable product."

Munger [1] comes somewhat closer to a consideration of the financial factors for a rotation of Douglas fir in pure even-aged stands in the Pacific Northwest.

From the quotations given, one fact stands out clearly: We are still groping more or less in the dark where choice of rotation is concerned, and we are even lacking the fundamentals upon which to base the principles to govern us in making a proper choice. It also appears that in many cases the term "actual felling age" should be substituted for rotation. Rotation in itself signifies return or succession in a series. Fernow [2] has warned, as early as 1905, against mixing up "actual felling age, the time when a stand is actually cut or to be cut, and normal felling age (rotation), the time when in a scheme of continued management it is proposed to have it cut again and again—a mere standard time. Few stands are cut in the age of the rotation determined for the forest as a whole." Where a "rotation" of yellow pine, for instance, of 200 years is advocated, it is evident that this can not be meant to constitute the fixed period at which yellow pine should be cut again and again in the future. It is really the actual felling age, the time when a given stand of yellow pine is actually to be cut in the future, not a succession of 200-year periods. The rotation itself will be much shorter, as European experience has shown us. Moreover, it is more than doubtful whether our successors in 200 to 400 years will pay much attention to the rules we may try to lay down for so remote a future.

CUTTING CYCLE.

The impossibility of predicting with even a modest degree of probability what will happen in the future and of anticipating changes in conditions of an economic nature is responsible for the vagueness with which the question of fixing definite cutting cycles is treated. Tentatively, cutting cycles of about 50 years have repeatedly been advocated for uneven-aged stands (mixed and pure) under the selection method, as a policy to be followed on virgin national forests. If present economic conditions should prevail in the next 50 years—that is, if the demand for timber should continue to fall far short of the actual annual increment—it would hardly pay a lumbering concern of the future to extend its operations to cut-over areas before 50 to 60 years had elapsed. Even then it seems doubtful whether the

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[1] Munger, T. T. The growth and management of Douglas fir in the Pacific northwest. U.S. Dept. Agr., Forest Serv. Circ. 175, 27 pp., 4 figs., 1911.

[2] Fernow, B. E. Forest terminology. *In* Forestry Quart., v. 3, no. 3, pp. 255-268, 1905. (See p. 264.)

amount of timber contained in the few overholders left as seed trees and in individuals at or just below the diameter limit established in a first cutting would prove attractive to purchasers of the future, provided always no change in the lumber market should take place. The diameter limit now fixed on many national forests may be said to be about 12 inches, varying somewhat with the species and local conditions. Few trees below this diameter will reach such dimensions in 50 years as to form a merchantable stand, judged by our standards of to-day.

If it is unwise blindly to take over principles and policies developed and more or less accepted in countries with old-established and far-advanced forestry and apply them to the first stages in the organization of our virgin forests, the study of the history of the forestry movement and development in other countries can not but be of the greatest practical value. We are justified also in assuming that the history of forestry will repeat itself and that forestry in all countries with large virgin or practically virgin forests in touch with the general market will run through the same phases of development as it did during the last centuries in central Europe, but at a very much faster pace, owing to the enormously enhanced facilities of transportation and marketing and the rapidly increasing demand for timber.

If this be true, a cutting cycle of about 50 years may prove too long. To judge from the development of timber values in Europe, our once cut-over stands should prove attractive in a shorter period.

In determining the duration of cutting cycles, it is reasoned that the accessible virgin timber in the national forests should be cut once before operations return to the first areas logged over. How much time this first culling may consume we have no means of telling. It should be remembered, however, that the system naturally presenting itself is that of selection cutting, and although there is a decided tendency toward heavier marking approaching clean cutting, this latter should be taken cum grano salis. Actually, the reproduction left includes all individuals up to and sometimes beyond 12 inches diameter breast high; that is, trees that have reached a considerable age and that in 50 years will have grown to what would be classed in European forestry as veterans.

CUMULATIVE RISK.

In fixing long-term cutting cycles, a most important point has not been sufficiently emphasized, namely, the "cumulative risk" from fire, windfall, frost, and so-called deterioration to which a given stand is exposed during so long a period. The longer the cycle the greater the ratio of risk. The unparalleled development of fire protection in the national forests of the United States, it is true, promises fairly to exclude actual destruction from fire on any large scale; but, as long as there will be fires from unpreventable sources (lightning), the risk in extended cutting cycles increases from year to year with the growth in value of the stand. The shorter the period in which a merchantable stand can be produced and turned into cash the smaller will be the risk of loss.

Loss from windfall is inevitable in many localities as a direct consequence of selection cutting. It is clear that the cumulative risk of a longer cycle is far in excess of a shorter one. Evidently, devastating windstorms are more likely to occur during a period of 50 years than during a shorter one. Moreover, the loss in cash value, even in single trees, from windfall is bound to be heavier in the older stands. The larger, bulkier, and therefore the more valuable the tree, if sound, the more it is exposed to windfall. Falling trees in brushing against their standing neighbors not infrequently cause more or less serious wounds by bruising or tearing off the bark.

The greatest risk, however, involved in the long cutting period is from "deterioration," so called.

In nature a steady process of elimination goes on. Of thousands of seedlings springing up together in dense growths, comparatively few reach sapling size, very few grow into poles, and fewer, even, to standards. This natural thinning through competition in the fight for soil, food, and light is furthered by various dangers to which the young plants are exposed, such as from certain insects, foliage and twig diseases, injury from mammals, snowbreak, frost, and drought. Later, the surviving members of the stand are confronted with dangers from the same and other sources, such as suppression, lightning, insects, frost, and decay. The elimination of the weaker members effects a selection of older, well-established individuals, some of which may still suffer from the competition of their thriftier neighbors, but are not forced out of the community, or, to use Fernow's[1] well-chosen terminology, trees which are "oppressed," not suppressed. As long as improvement cutting on a larger scale on the national forests is impossible, the percentage of oppressed trees will depend upon the length of the cutting cycle. Both these oppressed trees and their more favored companions are exposed to dangers from which their earlier life was free.

Frost does a good deal of damage; here we are less interested in the damage done to the foliage or to the bark than in those more or less long cracks in the wood which are caused by very low temperatures. In cold weather the wood cylinder shrinks more in a tangential than in a radial direction. Particularly at sudden low temperatures, when the volume of the outer layers decreases rather suddenly while the inner layers are still free from frost and have

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[1] Fernow, B. E. Forest terminology. *In* Forestry Quart., v. 3, no. 3, pp. 255-268, 1905. (See p. 266.)

shrunk but little, differences in internal tension will cause the outer layers to split vertically. With rising temperature the frost crack closes. Not always is the bark able to stretch sufficiently over a frost crack. Often the bark tears open, and if low temperature occurs again and again, the cracks will not be able to heal over and will remain open for many years, giving the air access to the heartwood and incidentally allowing spores of wood-destroying fungi to germinate and infect it. Even if no infection takes place, these frost cracks very seriously impair the value of the timber. The older and bulkier the tree the greater is the danger of frost-crack formation. The risk naturally increases with the length of the cutting cycle. Infection, of course, can take place only through open frost cracks; internal frost cracks, besides impairing the value of the timber, can not be without influence on the chemistry and physics of the wood.

Although lightning occasionally strikes the smaller trees, even poles and saplings, it is to be expected in the nature of things that taller trees will be more exposed to injury from this cause. Very little is known, so far, as to the actual damage done by lightning in our forests. Destruction of individual trees has been frequently reported, and Plummer[1] gives a series of illustrations of injury to forest trees from lightning. He treats, however, only of those very gross cases in which even the least educated eye will recognize the cause of the injury.

We know through Robert Hartig's[2] classical investigations, which were continued by Von Tubeuf, that destructive lightning is rare in comparison to the overwhelmingly greater number of cases of lighter injury from lightning, varying from more or less large wounds visible on the outside of the tree to the small and insignificant local killing of parts of the cambium and of the living bark which can only be detected by careful dissecting.

The symptoms of lightning injury in our forest trees are easily recognized from Hartig's excellent descriptions. They are particularly common and conspicuous in white fir.

For practical purposes, we have to consider here only those forms of lightning injury which in some way endanger the life, the health, or the commercial value of the tree; this will include not only actually destructive cases, but also very large numbers of lesser injuries. The accumulation of risk during a long-time cutting cycle becomes self-evident, particularly in view of the fact that the danger from lightning increases quite out of proportion to the increase in height of the tree and the development of the root system.

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[1] Plummer, F. G. Lightning in relation to forest fires. U. S. Dept. Agr., Forest Serv. Bul. 111, 39 pp., 16 figs., 1912.

[2] Hartig, Robert. Untersuchungen über Blitzschläge in Waldbäumen. *In* Forstl. Naturw. Ztschr., Jahrg. 6, 1897, Heft 3, pp. 97–120; Heft 4, pp. 145–165; Heft 5, pp. 193–206. 83 figs.

Hartig, Robert. Neue Beobachtungen über Blitzbeschädigung der Bäume. *In* Centrbl. Gesam. Forstw., Jahrg. 25, 1899, Heft 8–9, pp. 360–381, figs. 47–71; Heft 12, pp. 523–544, figs. 81–110.

Although young trees are also exposed to the attack of insects, it is clear that a colony of bark beetles will prove far more injurious in killing a merchantable tree than in killing a small pole. Moreover, certain insects seem to have a predilection for larger sizes. The probabilities of attack increase with the length of the cutting cycle. Besides, the older the tree and the more it has been exposed to wounding the more liable does it become to attack by wood-boring insects which materially reduce the value of the timber.

The timber contained in trees killed by lightning, as long as they are not destroyed, and in those killed by bark beetles may be utilized, and, with increasing timber values, will be utilized before they deteriorate.

The few veterans which have withstood the many dangers of earlier life do not go on living forever; they finally succumb like the rest.

It is still an open question whether forest trees are theoretically immortal and die only through the devastating influence of severe storms, lightning, insects, certain diseases caused by fungi, such as *Armillaria mellea* and *Fomes annosus*, or because the root system of the veteran finally has exhausted all available resources of the soil within its reach. As we are interested here only in the future of cut-over areas in relation to the length of the cutting cycle, it is unnecessary to enter into a discussion of this question. The cutting cycle for any one species will in all probability never be long enough to raise individual decadence from old age to the rank of an influencing factor. We should bear in mind, however, that individual decadence is not in itself deterioration unless decay sets in.

The importance of the reduction in the timber value of the tree through the agency of fungi, on the other side, can not be overemphasized. This reduction in timber affects either the prospective timber values—that is, the increment—or the present stock, or both. In the first case, the fungi in question (mostly Pyrenomycetes and rust fungi) inhabit living tissues of the foliage or of the young bark. The continuous drain on the assimilates of the foliage either in the leaves proper or on their way down through the bark is evidenced by a decrease in increment of the tree, which in long cutting cycles will represent a very considerable loss in timber values. In other words, trees affected with foliage or bark diseases will be far from yielding the timber we might expect from sound trees. It must be mentioned that losses in prospective values are not alone due to fungi; mistletoes and leaf-inhabiting insects are responsible for enormous deficits in yield. The economic rôle of the fungi, mistletoes, and leaf-inhabiting insects in our virgin forests is highly important and will remain so for a long time, on account of the difficulties connected with their control and even more on account of our very limited knowledge concerning their life histories and specific action. More intensive studies on the members of this group must be left to the future. At the present time we are more interested in the preservation of our actual timber, including such values as will be formed in the near future.

Actual timber values are seriously endangered by wood-destroying fungi, all of which belong to the Hymenomycetes. With the exception of a very few (*Armillaria mellea*, *Fomes annosus*), which in attacking living roots first cut down the increment of their host and then invade the wood of the bole, they all inhabit the heartwood and generally leave the sapwood intact. As the principal timber values are stored in the heartwood, the enormous damage they are able to cause is all the more in evidence. All of these fungi are adapted to given hosts or groups of hosts; these groups are seldom very large. *Polyporus amarus*, for example, the cause of the extremely destructive heart rot of *Libocedrus decurrens*, can not grow, as far as is known, in any other host species. *Trametes pini*, on the other hand, attacks a number of pines, Douglas fir, and other conifers. The composition of the stand, as well as the representation of species, is therefore an important factor in the ecology of these fungi. Only those fungous spores which land on trees of the species to which they are adapted have a chance after germination to enter into the tree.

Being strictly heartwood inhabiting, these fungi, with the exceptions mentioned above, can, of course, only attack trees which already have formed heartwood. But as they are unable to penetrate the bark, they are harmless unless their spores are carried on to some wound or opening (branch stubs) in the protective skin represented by the bark. The longer the host is exposed to wounding, the greater will be the chances for infection.

As might be expected, therefore, the losses from decay in standing living trees are enormous in virgin forests. Even in the best managed forests of Germany losses from decay are heavy. Möller,[1] in figuring the damage done by *Trametes pini* in the pine forests of the Prussian Government, arrives at the astounding figure of more than 1 million marks (about $250,000) annual loss from this source alone. In the period from 1905 to 1908 the Prussian Government spent $87,480 in the control of *Trametes pini* in its pine forests.[2] In 1914 this sum had increased to about $120,000.[3]

In American literature no reliable figures are available relating to the annual loss from decay in standing timber in virgin forests. Such figures can be obtained only by exact studies on representative areas, the methods of which the writer has been trying to work out

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[1] Möller, A. Über die Notwendigkeit und Möglichkeit wirksamer Bekämpfung des Kiefernbaumschwammes Trametes pini (Thore) Fries. *In* Ztschr. Forst- u. Jagdw., Jahrg. 36, 1904, Heft 11, pp. 677–715, pls. 4–5.

[2] Möller, A. Der Kampf gegen den Kiefernbaumschwamm. *In* Ztschr. Forst- u. Jagdw., Jahrg. 42, 1910, Heft 3, p. 133.

[3] Möller, A. Der Kampf gegen den Kiefern- und Fichtenbaumschwamm. *In* Ztschr. Forst- u. Jagdw., Jahrg. 46, 1914, Heft 4, pp. 193–208.

during the last few years. In reason, all figures relating to loss in timber from decay, insects, lightning, etc., should apply only to such forested areas as are accessible at present or which will be in all probability accessible in the not too remote future. Inaccessible stands, whatever their protective value, do not represent timber values, and it is obviously wrong to include them in any estimate of the damage done to our timber stock on hand.

The rate of progress of decay in the individual tree is altogether unknown beyond vague guesses.

Hartig [1] has tried to figure the rate of growth of the mycelium, for instance, of *Fomes igniarius*. Möller [2] has made an attempt to figure the rate of growth of *Trametes pini* and resulting decay in *Pinus silvestris* from actual measurements in artificially infected trees. It is clear that unless such experiments are carried over a great many years, only the rate of growth of juvenile fungus plants starting from the infection can be measured, which can not be taken directly as a guide for figuring the growth of the older or mature fungus plants. Besides, the experiment is based upon the assumption that the fungus, after once having gained access to the interior of the tree, is independent of possible individual differences of its substratum, or, in other words, that the rate of growth is a fixed factor, irrespective of individual properties of the heartwood. This assumption has no solid basis. The rate of growth of the fungus plant, and therewith of decay, is undoubtedly one of the most inaccessible chapters of forest pathology, on account of the difficulty in finding a stable point of issue. There is at present no reliable method known of determining the actual extent of decay in the standing living tree. Indirect methods are the only means presenting themselves to-day; they leave much to be desired with regard to accuracy and can not be expected to yield results unless carried on over a long period.

What we do know is that decay in standing living timber from heartwood-destroying fungi causes very heavy losses and that decay is progressive. Sporophores develop on decaying trees, and the disease spreads through spores from one tree to other individuals of the same and sometimes of other species. Moreover, the decay starting from an incipient infection progresses in the heartwood of the individual tree until its most valuable lumber is destroyed. Decay being progressive, the cumulative risk from this source in long cutting cycles is therefore far greater than in the case of lightning or other injurious agents.

Unlike insects, heartwood-destroying fungi have few or no natural enemies; there is no such thing as "biological control" of decay.

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[1] Hartig, Robert. Die Zersetzungserscheinungen des Holzes der Nadelholzbäume and der Eiche ... p. 116. Berlin, 1878.

[2] Möller, A. Der Kampf gegen den Kiefernbaumschwamm. *In* Ztschr. Forst- u. Jagdw., Jahrg. 42, 1910, Heft 3, pp. 129–146. (See p. 145.)

PERIOD OF TRANSITION.

American forestry stands now at the very beginning of a period of transition from the handling of virgin forests to actual forest regulation. The most urgent problem, therefore, consists in how to take care of our forests as we have them, with all their defects, with individual decadence and decay, and to leave them to future generations in as favorable a state as possible, judged by our very limited insight of to-day. At the present time the only means at the disposal of the Government to carry out any plans in forest regulation based upon what appears to us as sound silviculture is through timber sales. The Government does not and can not cut its own timber. It is therefore entirely dependent upon a highly variable outside factor with regard to the most important part of its silvicultural work, a factor over which it has but little control. All attempts at the regulation of yield must then be concentrated on timber-sales areas. A comparison between the area actually cut over annually and the total national-forest area that may eventually become accessible to logging operations will show the severe hardship under which the Government is forced to work. Moreover, timber sales do not always occur where they are most needed from a silvicultural point of view, nor do they always cover the entire natural units upon which it is desirable to prepare for a system of regulation. A comprehensive system of regulation on a larger scale following natural units is out of the question as long as the Government is not in a position to do silvicultural work on its own land where it is most needed.

The aim of the Forest Service at the present time consists less in how to do the greatest amount of good to future generations than in how to do the least harm and at the same time to do justice to our present-day conditions. Instead of exhausting our energies in sterile speculation of what might happen in 100 to 200 years from now, there is a strong tendency toward applying them first to the analysis of the most urgent needs of to-day and then to the exact and painstaking study of all the innumerable factors which enter into a comprehensive plan for the future structure of American forestry. It is well to remember that so far, not even the methods leading to the majority of such studies are worked out. The necessity of taking care of our present-day timber supply and of providing for the future in an extensive rather than intensive way has found strong expression in Chapman's[1] "American Method," where regulation is based not only on present volume and annual growth, but also on the "actual condition and amount of timber in the different age classes, with approximate knowledge of the behavior and condition of the age classes for an

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[1] Chapman, H. H. Coordination of growth studies, reconnaissance and regulation of yield on national forests. *In* Proc. Soc. Amer. Forest., v. 8, no. 3, 1913. pp. 317-326. (See p. 323.)

extensive future period." If "condition" is defined as state of health, not only as far as thriftiness of growth is concerned, but also with special regard to degree of merchantability as influenced by decay, the condition factor becomes a subject of pathological study.

Condition of the timber we hope to raise for the future, in the definition as given above, has a strong bearing on the possible regulation of yield. There can be no sense in figuring cutting cycles or rotation for future generations to follow unless we assume that our successors will find the area we have cut over covered with a stand not only apparently but really merchantable; in other words, with timber that is not rendered valueless by decay. The most ingenious speculation as to future yield is without any value whatever unless we have some way of figuring how long the steadily increasing but admittedly perishable timber stock can be left in the forest before it is liable to destruction by fungi.

The most important problem before us, therefore, is the determination in definite values of the condition of timber stock, present and future.

CONDITION OF TIMBER STOCK.

The condition of the timber as a factor in regulation may be expressed as the relation of the volume of timber destroyed or rendered unmerchantable by injurious agencies to the ideal volume of merchantable timber; or, in so far as forest regulation is interested not merely in the present but in the future, as the relation of the mean annual total loss to the mean annual increment.

It has already been pointed out that the concept of the relation of the mean annual total loss to the mean annual increment is without any value whatsoever as long as both factors are unknown. We are beginning to know in a small way something about the mean annual increment of certain species in certain types of some of the national forests. We are still completely ignorant as to the influence that the only silvicultural act of any importance open to the Forest Service, that is, cutting on timber-sales areas, will have on the increment of the remaining trees. This knowledge will come in due time. The value of the total-loss factor is altogether unknown. In order to attack this problem it is necessary to analyze it, to reduce it to its several components, and to study each in its turn. By synthesis the total loss can then be computed and the true relation to increment determined.

TOTAL LOSS.

The analysis of total loss already given shows that its components are known, but not their values. Of all these components the most important, the one that has the strongest bearing on the value of the stock of timber at hand, is loss from decay or heart rot caused by a group of heartwood-destroying fungi. Very young trees are not susceptible to heart rot. No heart rot is possible before heartwood is formed. Unfortunately, we do not know anything about the formation of heartwood in our American species with relation to the age of the tree. The younger trees, while at present immune, will, in growing up and after formation of heartwood, become just as subject to heart rot as are their older companions. It is, then, of prime importance to know at what age living trees of a given species become particularly liable to attack from the one or more heartwood-destroying fungi that use their heartwood as a source of food. It is, further, of the utmost importance to know whether there are any conditions in the tree or outside of it that exert an influence over the development of the fungi once they have gained access to the heartwood of a tree to which they are adapted.

Beyond general statements to the effect that overmature trees do deteriorate from heart rots, very little information is to be gathered from American literature concerning the average age at which certain tree species become liable to attack from heartwood-destroying fungi. Greenamyre[1] mentions that in the Apache National Forest the decay in Douglas fir ''no doubt largely offsets the growth'' after the age of 210 years is reached.

Munger[2] gives a little more specific information:

> The amount of decay found in living Douglas firs up to the time they are 150 years old or so is very small, but in mature and overripe timber there is a great deal of defect due to decay. . . . Douglas fir trees resist infection from fungi well until they become mature, when, because of the opening up of a stand, breakage, and scars due to the action of the elements and of fire and insects, and also because with advancing age their resistant power becomes less, they offer entrance to fungi.

It is not clear from the context whether Munger's figures are an estimate or are based on actual methodic investigation and measurements.

Findley Burns,[3] in speaking of conditions on the Crater National Forest, gives the following information:

> Many of the older Douglas firs are affected by a dry rot. . . . White fir is especially susceptible to decay, and many trees above 40 inches in diameter on the forest are so rotten as to be valueless, even for cordwood.

In the latter case, age is supplanted by diameter, which answers perfectly well if diameter invariably corresponds to age.

Barrington Moore and R. L. Rogers[4] incidentally give some interesting notes on the age of infection of balsam fir, which on the

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[1] Greenamyre, H. H. The composite type on the Apache National Forest. U. S. Dept. Agr., Forest Serv. Bul. 125, 32 pp., 4 figs., 1913. (See p. 31.)

[2] Munger, T. T. The growth and management of Douglas fir in the Pacific Northwest. U. S. Dept. Agr., Forest Serv. Circ. 175, 27 pp., 4 figs., 1911. (See p. 10.)

[3] Burns, Findley. The Crater National Forest. U. S. Dept. Agr., Forest Serv. Bul. 100, 20 pp., 4 pls., 1911. (See p. 12.)

[4] Moore, Barrington, and Rogers, R. L. Notes on balsam fir. *In* Forestry Quart., v. 5, no. 1, pp. 41–50, 1907.

area investigated was 50 years in pure stands and 85 years when mixed with hardwoods. They speak of butt-rot only, without specifying the cause; unfortunately, the numerical basis from which their figures are derived and their methods are not given.

The bearing on management of the age at which decay becomes a seriously damaging factor is very rarely realized.

Clapp,[1] in speaking of incense cedar and white fir, clearly recognizes that where these ''inferior'' species are also defective, ''an attempt should be made, at least in selection stands, to reduce their rotation to one which will produce sound timber.''

In a recent article, D. T. Mason [2] advocates a rotation of 100 years for western white pine, on the ground that this species on the average gives a maximum yield at this age and that from about the same age fungi, and particularly insects, generally succeed in doing a large amount of damage.

It would serve no purpose to continue quoting the few and scattered notes on the relation of age to decay, of a similar indefinite nature found in American literature. By way of consolation, it may be said that foreign literature does not abound very much more than our own in definite information regarding this point. Although the importance of the age at which forest trees are most liable to attack from heartwood-destroying fungi is frequently hinted at in German literature, Martin [3] is the only German forester who, to the knowledge of the writer, has given more than a cursory discussion of the relation of this age to rotation. In speaking of the immense damage done in Prussian pine forests by *Trametes pini,* he attempts to show from somewhat meager material how the increase in loss from this cause should lower the rotation.

All computations of the amount of decay in German forests must necessarily be incomplete, since from an early age all undesirable individuals, including, as a matter of course, all trees with visible signs of decay, are eliminated in improvement cuttings. The result is a stand of a comparatively high degree of soundness. Even in such stands Martin finds (p. 688) that in a given district the percentage of decay in wood good for fuel only in the 100-year class was 11, in the 120-year class 22, in the 130-year class 31, in the 140-year class 37, and in the 160-year class 42. He points out that in unsound stands the felling age must be lowered in order to secure the maximum income. Martin [4] again discussed similar ideas in 1910.

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[1] Clapp, E. H. Silvicultural systems for western yellow pine. *In* Proc. Soc. Amer. Forest., v. 7, no. 2, pp. 168–176, 1912. (See p. 175.)

[2] Mason, D. T. Management of western white pine. *In* Proc. Soc. Amer. Forest., v. 9, no. 1, pp. 59–68, 1914.

[3] Martin. Der Einfluss des Baumschwammes auf die Umtriebszeit der Kiefer. (Kritische Vergleichung der wichtigsten forsttechnischen und forstpolitischen Massnahmen deutscher und ausserdeutscher Forstverwaltungen.) *In* Ztschr. Forst- u. Jagdw., Jahrg. 35, 1903, Heft. 11, pp. 685–690.

[4] Martin. Die Umtriebszeit der Kiefer in den Staatsforsten von Preussen, Bayern, Elsass-Lothringen, Hessen und Anhalt. *In* Forstw. Centrbl., Jahrg. 54, 1910, Heft 7, pp. 363–387.

Möller[1] touches upon the same point in a general way, without trying to give the problem a more solid basis by exact material. The following sentence is worth quoting:

> Whilst the mean annual increment of the stand is slowly decreasing, the mean annual increment of decay is steadily on the increase.

Here is the clue to the proper silvicultural valuation of cutting cycles or rotation on a pathological basis. The time at which a tree or a stand is to be cut may range from a comparatively low age to the age of maximum production of lumber, according to the special needs the forester has in view; but the upper limit of this range should not lie beyond the period at which the gain from increment is offset by loss from decay, irrespective of the ideal amount of timber a sound tree or stand might produce under favorable conditions. Not to cut a tree or a stand in which increment is offset or exceeded by loss from decay, where cutting is possible, constitutes an unsilvicultural act. Gilman[2] informs us that silver fir in the Black Forest, Baden, Germany, "is unable to stand a long rotation, for after 100 years the per cent of rotten timber increases greatly." Here, the influence of loss from decay on rotation is clearly shown; but it is to be noted that the loss factor is derived in a purely empirical way and is not based on exact studies. Hemmann[3] has published some interesting and exact studies on the damage done by *Trametes pini* in Scotch pine in a small area under regular management; that is, where the disease was partly eliminated by improvement cuttings.

All this somewhat scanty European material, valuable though it undoubtedly is for transatlantic forestry, is of very little help to us. What holds good for the managed forest raised in a century of careful nursing can not serve for more than a clue in genuinely or practically virgin forests, whether they be located in the United States, in Canada, in Chile, in India, or in Siberia. Again we are confronted with the necessity of working out our own problems in our national forests.

INFERIOR SPECIES.

Most of the timbered parts of the national forests, especially in the West, are practically virgin, seriously injured by fire, composed of even-aged or many-aged stands, and generally of more than one species, which are more or less exposed to heart rot caused by one or more specific fungi.

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[1] Möller, A. Über die Notwendigkeit und Möglichkeit wirksamer Bekämpfung des Kiefernbaumschwammes Trametes pini (Thore) Fries. *In* Ztschr. Forst- u. Jagdw., Jahrg. 36, 1904, pp. 677–715. (See p. 712.)

[2] Gilman, E. C. V. Forest types of Baden. *In* Forestry Quart., v. 10, no. 3, pp. 440–457, 1912. (See p. 452.)

[3] Hemmann. Über den Schaden des Kiefernbaumschwammes. *In* Allg. Forst- u. Jagdztg., Jahrg. 81, pp. 336–341, 1905.

A systematic study of the relative position occupied by the heart-rot factor in the economy of the forest presupposes a knowledge of the morphology and biology of the specific fungi attacking the species of which the forest is made up. Morphologically, most fungi of economic importance are well known; biologically, there is much left to be learned. The susceptibility of each host species to specific attack, the age at which a given species becomes liable to attack by the fungi adapted to live on it, the age at which a given species is liable to suffer appreciable loss from this source, the relation of accessory factors in the tree and outside of it to fungus growth, the relative loss caused by each fungus in its specific host—all these are fundamental problems which must be solved for every important fungus on every commercial species of our forest trees. So far, no definite and clear, comprehensive answer can be given to any one of these questions.

In determining upon a suitable starting point in the overwhelmingly large amount of work before us, the question is that of deciding where such work is most needed at the present time.

Leaving out of consideration such species as bigtree (*Sequoia gigantea*), which is never cut in national forests, and redwood (*Sequoia sempervirens*), which is hardly represented in national forests, the commercial timber of the national forests in the western part of the United States is composed of coniferous trees, such as pine, larch, spruce, fir, Douglas fir, hemlock, incense cedar, and western white cedar. They constitute the goods the Government has to offer for sale. Of these the pines cause least trouble. Pine lumber is eagerly sought and pays good prices; moreover, the loss from decay is comparatively small. In Government timber sales there is never any difficulty about pine timber; the more the Government has to sell on a given tract the better. Not so with the so-called "inferior species."

The term "inferior or undesirable species," as it is generally applied, is originally not a technical one. It is meant to designate those more or less heavily represented commercial species which suffer from a distinct prejudice on the part of the purchaser. If we could grow sound incense cedar, for instance, there would be a ready market and a good price for every foot, board measure, of it that the Government could offer on timber sales. Distinction should be made between species which actually yield technically poor lumber, even if sound, and species, on the other hand, which when clear and sound yield valuable material, but which are in general underrated by the purchasing public on account of the extraordinary prevalence of decay. An example of the first class is eastern hemlock. An example of the second class is incense cedar, which, although of excellent quality when sound, suffers from a very bad reputation among lumbermen, because it is so very commonly rendered useless by dry-rot or pin-rot. The numerically and economically most important species of the accessible merchantable national forests in southern Oregon and California are sugar pine, Jeffrey and yellow pine, Douglas fir, white fir, and incense cedar. To these may be added, for certain localities, lodgepole pine, red and Shasta firs, western larch, Sitka spruce, western hemlock, and western red cedar. Of the six main species, all three pines command good prices. They are comparatively free from heart rot. White fir and incense cedar are in general so badly defective that, as Clapp[1] states, they are "under present conditions almost a drug on the market." Douglas fir stands in a class by itself. The value of its timber is well known; in fact, it competes with pine timber as far as quality for many purposes is concerned. On the other hand, Douglas fir is in a far higher degree susceptible to the attacks of several heartwood-destroying fungi, and, although it is not classed among the inferior species, the very prevalence of decay makes it less desirable than the pines, from a silvicultural point of view.

Incense cedar and white fir are frankly classed as inferior. Whether this view is correct or not, we must reckon with it as a powerful factor of influence in all timber sales where these species occur. They are the lower grade by-products of the factory, the production of which can not be stopped; it goes on in spite of what we may wish or what we may do. The logical conclusion appears to be, then, to concentrate all efforts on detailed and comprehensive studies of the properties of these by-products, desirable or undesirable, and to incorporate the results in a rational system of management, rather than to attempt to stop their production. The attitude of American foresters toward these and similar species is undoubtedly changing. There was a time when they were considered little better than weeds, to be gotten rid of as soon as possible and to be kept out of the forest wherever possible. This concept is giving room more and more to a consideration of how best to regulate the unavoidable reproduction of both species and how best to utilize the timber they produce.

The so-called inferior or undesirable species have their very definite place in the ecology of the mixed forest, and many examples could be cited from European experience of the disastrous results of an artificial change in representation of species and reduction of the mixed stand to a pure stand composed of an apparently more desirable species, without due consideration to the local soil and climatic conditions. Greeley[2] seven years ago expressed the opinion that "it is

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[1] Clapp, E. H. Silvicultural systems for western yellow pine. *In* Proc. Soc. Amer. Forest., v. 7, no. 2, pp. 168-176, 1912. (See p. 175.)

[2] Greeley, W. B. A rough system of management for forest lands in the western Sierras. *In* Proc. Soc. Amer. Forest., v. 2, no. 2, pp. 103-114, 1907. (See p. 112.)

both impossible and undesirable to eliminate these species altogether." He specifically names white fir and incense cedar. Their aggressiveness makes it impossible to eliminate them, even if this were desirable. But more than one species, not so many years ago considered inferior, has now come into its own. The history of the lumber markets of Europe and our own country shows conclusively that with closer utilization necessitated by the growing scarcity of timber, the value of lower grades, as well as of so-called inferior species, is advancing more rapidly than that of upper grades or more valuable species. In the case of incense cedar this evolution may be watched at the present time. Up to a very short time ago incense cedar was "almost a drug on the market;" now even very short logs when sound are utilized for pencil wood and priced accordingly.

Concentration of study on the inferior species, therefore, promises the most immediately applicable results.

METHODS OF INVESTIGATION.

CHOICE OF SPECIES AND SITE.

Forestry is not interested primarily in the morphology and life history of a given heartwood-destroying fungus. Such studies, though indispensable and of the highest value, belong to an altogether different realm of science. The forester thinks in terms of trees, not of fungi; he concentrates on timber species to be protected or utilized, not on parasitic organisms, however interesting they may be from a mycological point of view. If forest pathology is ever to be of any value to practical forestry, all work and all conclusions must be focused on the tree, the species, as a producer of timber values and as a member of the forest community.

The fact that the same species may be subject to serious loss from several fungi and that the same fungus often works differently in different host trees complicates the difficulties naturally connected with all work for which a basis first had to be constructed. Partly for this reason, the writer first worked on incense cedar, which, so far as known, has only one heartwood parasite, *Polyporus amarus.* The studies described in the following pages were concentrated on white fir, because its management presents, perhaps, the most embarrassing problem of to-day on the Pacific coast and because, in by far the greater number of cases, serious loss is caused by one fungus only, *Echinodontium tinctorium.*

After deciding upon the species to be investigated, the choice of the sites for the study becomes the main question. One single type will probably yield interesting clues, but the result can not with impunity be applied to all sites and types within the range of the species. It is clear that studies within what might be termed the merchantable range of the species must be most important from a practical point of view. But inside of the merchantable range the species is subject to so many varying conditions with regard to soil, climate, admixture of the species, and representation that here again typical areas must be chosen for independent studies. The more diversified the types studied and the greater the number of trees per type and in the aggregate, the more reliable will be the results.

The choice of the particular area to be studied is, of course, important. The unit of study should be representative, typical for the larger unit. In general it will not be difficult, with some care, to make the proper choice.

The result of the writer's studies, still unpublished, on the critical age of incense cedar served to work out the methods which should be applied in a modified form to the at present more important investigations on white fir. European precedent could not be used; Martin, Möller, and Hemmann worked on managed forests. New methods to suit our conditions had to be evolved.

The only satisfactory result could be expected from careful dissection and analysis of as large a number as possible of trees of different ages. Unlike other investigative work, studies of this kind can not well be carried out on timber-sales areas where the actual felling and bucking of the trees is done by the purchaser. The purchaser is none too willing to cut trees containing rot unless he is compelled to do so; much less does he care to buck such trees, which, after all, are the ones from which we must expect most valuable instruction. He is not obliged to cut trees below a certain diameter limit, which, of course, can not be left out. All this is particularly true for the so-called inferior species, the handling of which often comes so near being a loss to the purchaser that any additional cost would work a distinct hardship. For the same reason it is impossible to have the trees on timber-sales areas bucked in odd log lengths, as dictated by the irregular and varying extent of the decay. As will be seen, a few of the notes used for this study are incomplete, because they had to be taken in connection with timber sales.

It becomes necessary, therefore, to carry on investigations of this kind on representative areas chosen for the purpose and to have the systematic cutting and dissecting of the trees done by crews, involving much work and a large expenditure. This way of handling the problem has proved to be the only feasible one; and, as long as immediate results may be expected, which if properly applied must lead to very considerable savings as well as to progress in silvicultural management and forest regulation, the expense and work seem to be justified.

FIELD METHODS.

Before the actual felling begins, notes are taken first on the larger forest unit of which the area to be studied forms a part, such as elevation, climate, water table, soil in general, history (lightning and forest fires), composition, representation of species, ground cover, possibilities of future logging operations as a first step toward regulation, and local valuation of the species; more detailed notes of a similar nature then describe the particular type and stand which is the object of the study.

When a new species is to be studied, trees of all sizes and all conditions must be cut. It is absolutely necessary constantly to guard against picking out trees either because they appear sound or because they are liable to contain decay. According to the attitude of mind of the investigator there will always be a tendency, conscious or subconscious, to think of the final result and accordingly to choose particular trees for felling. The personal factor must necessarily influence the result of the equation and can not be warned against too emphatically.

Correctness and accuracy in detail are the basis of any scientific work worthy of the name. Where the one chief aim is to substitute reliable figures for guesswork, to establish facts, from which conservative interpretation may derive certain working rules, observations and measurements can not go too far in detail and exactness. On the basis of experiences in the incense-cedar studies, a printed sheet was prepared, to be used in a loose-leaf binder of pocket size, in which a set of standard notes was to be entered. Each sheet contains the notes for one tree only.

The first notes to be taken on a tree chosen for analysis are general; they are taken before the tree is felled. Slope, exposure, soil composition, and moisture are taken for the individual tree; the next notes concern the outward appearance of the tree, crown class, as far as can be determined, condition of the bole, whether forked or leaning, presence and degree of fire scars, resin flow on butt or bole, swellings, sporophores of fungi, condition of the crown, development and state of health; in short, all notes that can and should be taken from the standing tree. During this time an assistant takes the diameter breast high and sets the fellers to work. The notes on the bole and crown are completed when the tree is down. They concern the presence of mistletoes or needle diseases, witches'-brooms of any kind, their number and relative importance, presence and extent of lightning injury, condition of top, and similar data that might have a bearing on the pathology of the species. It goes without saying that the tree is felled at the regulation stump height of 18 inches, never higher unless absolutely unavoidable. The assistant now measures the height of the tree from the ground and counts the age at the stump. This, of course, does not give the true age; but instead of adding, more or less at random, a small number of years corresponding to the height of the stump, it seems advisable to accept the count at the stump as the age. The fewer the figures based on an estimate that are included in our computations, the narrower will be the margin of error. Besides, in practical work, the age is generally counted at a stump height of 18 inches, and, since for all purposes of management we have to deal with the standing tree where diameter is the only indicator of age, it is of little importance whether the age counted is absolute, within narrow limits, as long as all figures are directly comparable with each other. Moreover, in practice it is impossible to have all trees cut at exactly 18 inches. With the greatest of care, the stump height will vary. It is an easy matter, where desired, to add a number of years corresponding to stump height as soon as reliable figures, which now are lacking, are obtainable.

The limbs and branches are now lopped off and the brush piled for burning.

In the bucking of the bole some judgment should be used, guided by the object of the study. We want to find all traces of decay in the bole and take exact measurements of them. Obviously, then, the aim of the dissection must be to open up the tree in such a way that no decay can escape the observer. It would not do, therefore, to buck all trees in even log lengths of the usual commercial measures. A straight, clean bole without any blemish whatever is bucked in 16-foot logs, which then are individually split; this will, as a rule, bring out any hidden decay. Both the cross sections at the opened surfaces of the split wood must be searched very carefully for any abnormal sign. This makes full knowledge of the properties and aspect of the normal wood a prerequisite. In the beginning, therefore, it is advisable first to study very closely the sound, normal wood of the species, until the operator is able to detect at a glance and automatically any deviation from the normal. The success of the study hinges upon the development of personal skill in judging wood. In order to prevent the dulling of this sense during the course of the work, check studies of perfectly sound wood will prove very beneficial. Any slight real or apparent deviation from the normal in physical properties or aspect, particularly in color, must be followed, of course, to its source.

Trees without any blemish are rare; generally there is either some irregularity in form, fork, unusually heavy branching, or there are sporophores of fungi, badly healed-over branch stubs, swellings, depressions, catfaces, fire scars, lightning scars, or frost cracks and frost ridges. In choosing the proper places for bucking, it is generally advisable to start at the most salient malformations or defects; they will often lead to the focus of decay, if there is any. In case of failure, the less prominent defects are investigated, and so on down the line until there is no doubt left that no decay is present in the bole. Particular attention must be given to branch stubs, which, by extending through the sapwood to the outside of the tree, offer an easy entrance into the heartwood. After infection has taken place in this manner, the mycelium grows in the heartwood. Before sporophores are formed it is often impossible to locate the presence of the mycelium in the tree. This is particularly true for quite young fungus plants, and the possibility that the beginnings of decay may be hidden in a log, both ends of which are perfectly sound, must ever be present in the mind of the operator. It is impossible, except by mere chance, to detect the very first stages in the field. As soon as the fungus plant, the mycelium, has reached a certain stage of development, represented by visible alterations of the wood, there is no excuse for overlooking it. As a rule, the oldest part of the focus of infection shows the strongest evidence of fungus growth expressed in what we call decay. Decayed stubs are a valuable index as to decay in the tree, although there are cases where, for unknown reasons, the infection does not, or only very slowly, result in more extended decay. Duesberg[1] has advocated the location of infected trees by the presence of diseased branch stubs. Such decayed branch stubs may also correspond to that stage of development of the mycelium just before the formation of sporophores through the stub takes place. In this case also decayed branch stubs will be most valuable in detecting heart rot in the bole.

If decay is found, it is followed throughout its entire extent by splitting the logs with wedges and with the ax. To avoid this often very tedious and time-consuming work, splitting with black powder has been tried, with rather unsatisfactory results. In partly decayed logs the splitting is very irregular, and the wood surfaces are badly stained and blackened, the stain generally interfering with the inspection of the wood. When the full extent of the decay is determined, notes are taken on the character of the discoloration or decay and on the stage of development, and the extent is carefully measured. For studies of this kind it will often be sufficient to note the extent in length in linear feet, under the assumption that in low-priced species any lumber that might be cut from an affected part of the bole will not pay for its transportation to the mill. In higher grade species the lateral extent must always be considered.

This complete and detailed dissection usually allows the tracing of the decay to some point of entrance, whether fire scar, lightning wounds, frost cracks, or branch stubs. The result is entered on the sheet. Finally, any notes not specially foreseen on the sheet are entered under "Remarks."

As a general principle, all observations that can be expressed numerically must be given in figures. It is essential that all esti-

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[1] Duesberg. Das Aufsuchen von Schwammbäumen in Kiefernbeständen vor der Ausbildung von Fruchtkörpern. *In* Ztschr. Forst- u. Jagdw., Jahrg. 44, Heft 1, pp. 42–45, 1912. Reviewed in Forestry Quart., v. 11, p. 251, 1913.

mating should be reduced to a minimum. In order to render this unavoidable minimum, which undoubtedly constitutes a source of error, as innocuous as possible, the operator must constantly be on the guard against any variations of his standard by which he is guided, consciously or subconsciously, and from time to time check up on this standard. The notes to be taken by estimate concern degree or grade. Soil moisture, seriousness of wounding by fire, degree of resin flow (whether light or heavy), condition of crown (for example, unhealthy color or thin foliage and the presence and degree of needle diseases in their bearing on the thriftiness of the tree), degree of discoloration of the wood—all these can be expressed in figures only with difficulty. Even if a scale of 1 to 10 is adopted for these purposes it is extremely difficult to decide whether the change of color of the wood under the influence of the fungus is to be classed as 6 or 7. The writer therefore has adopted a simpler system, which, while far from being exact, at least avoids gross errors and at the same time is graphically clear and sufficiently elastic to cover all cases of importance. It expresses the information asked for on the sheets with the aid of crosses and dashes. A dash after "Fire scars," for instance, is negative; there is no fire scar. One cross, x, is simply affirmative; there is fire injury, but it is not to be considered as serious. Two crosses, xx, indicate that the fire injury is fairly bad, distinctly beyond the mere presence of an injury. Three crosses, xxx, emphasize the damage; the fire injury is unusually large and severe. By putting the crosses in parentheses, (x), or x (x), or by hyphenating two consecutive degrees, x-xx, intermediate grades may be given when desirable; and finally the last grade, xxxx, can be used in very extraordinary cases for emphasis. In general, x, xx, and xxx will answer the purpose. Thus, the estimate is really reduced to a simple system of three grades, which allows for a more constant mental reference to the standard. Whenever necessary or feasible, special notes or measurements are entered after the crosses. This system is also used in our tables. With the exception given above, all these notes are taken by the chief of the party. Meantime, the assistant counts the age and diameter at every cross section, takes growth measurements, measures the width of sapwood and the length of the sections, and records such other data as may present themselves in the course of the work.

In complicated cases, drawings or notes are added on blank sheets bearing the numbers of the trees.

PATHOLOGY OF WHITE FIR.

The studies on white fir presented in the following pages are not meant to give definite results valid for the entire range of the species. They were primarily intended to develop the more practical methods to be employed and secondarily to gain reliable material to be used in a chain of similar studies on different types, from which conservative interpretation may derive final conclusions. They are given here as examples only, as illustrations of the general considerations presented in this bulletin. Since making these studies, others on a larger scale and on different types in different parts of the range of white fir were carried out with improved methods during the summer of 1913.

A short review of our present knowledge of the pathology of white fir will be of help in the discussion and interpretation of the data presented in this paper.

White fir (*Abies concolor* (Gord.) Parry) can not be called a decadent species; on the contrary, it is very aggressive and possesses remarkable elasticity and resistance to injurious influences. Its tolerance to shade is well known. Not only does it survive dense shading to a high age but it responds readily to light and then reaches considerable diameter and height in perfect health, provided it has not been seriously wounded and infected. The oldest tree examined in this study was 258 years old; it was badly suppressed and but 67 feet high with a diameter breast high of 17.4 inches. In the trees tallied between the ages of 130 and 140 years, the diameter breast high varied from 8.8 to 30.7 inches and the height from 47.5 feet to 125 feet.

In speaking of tolerance which allows suppressed trees to reach a high age under the most unfavorable conditions and with a minimum of annual growth, the behavior of the species with relation to light is generally meant; but this toning down of the life functions of the tree, visibly expressed in growth, very often has nothing to do with lack of light. A tree may become suppressed to the lower limits of its tolerance by any agent severely attacking any of its vital organs. Of these, the organs of the crown are both most easily accessible and most sensitive; hence, the heavy damage resulting from a serious attack by insects devouring and killing the foliage or by leaf-inhabiting fungi. White fir is subject to a disease of the foliage caused by *Lophodermium nervisequium*, which often kills all needles except those of the current year's growth. The loss in foliage surface, and therefore in photosynthetic capacity, may suppress a white fir just as lack of light would. Witches'-brooms caused by *Peridermium elatinum* on white fir are not common. They are very rarely of such development on the tree that they should be classed as an injurious factor to be reckoned with. Incidentally, it should be mentioned that the swellings and cankers so commonly connected with *Peridermium elatinum* on *Abies pectinata* in Europe are unknown in *Abies concolor*. On the other hand, very similar swellings and cankers caused on white fir by *Razoumofskya abietina* Englm. are extremely common. The actual connection is readily established by either the living mistletoe growing out from the swellings or by the small cuplike remains of the stem bases. The swellings render the affected part of the bole unmerchantable. When they break open into what are termed cankers, infection by fungi very readily takes place and a focus of heart rot forms, very much as in the case of *Peridermium elatinum* on *Abies pectinata* where *Polyporus hartigii* and *Agaricus adiposus* [1] commonly start from cankers caused by the rust fungus.

The mistletoe cankers very often are the cause of white-fir stems breaking off in a storm, just as Peridermium cankers affect *Abies pectinata.* This mistletoe is more generally found in the middle or lower parts of the crown; infection takes place only on the very youngest twigs.

Another mistletoe (*Phoradendron bolleanum* (Seeman) Coville) nests high up in the top. It often kills the leader; volunteers spring up, which are frequently killed in their turn. Considered in its relation to the totality of leaf functions, the loss from a killing of the leaders can not be very serious, although it may count in combination with other injurious agencies. The same is true for the host of minor parasites and injuries to which the peripheral growing parts—in contrast to the column of wood—are exposed.

We have seen that the wood of the living tree itself is generally immune to attack from heartwood-destroying fungi as long as it is protected by bark and sapwood. The few exceptions, it seems, are of no great importance in the case of *Abies concolor.* *Pholiota flammans* is not uncommonly found in white fir and seems to take the place of *Armillaria mellea.* The exact damage done is still to be studied. *Fomes annosus* is not yet reported on white fir to the writer's knowledge. *Polyporus schweinitzii* is not common on the species. All other fungi causing decay can not enter the living tree except through some opening, as far as is known at present.

In white fir, as in other coniferous trees, small superficial wounds are readily covered over with resin from the bark; this natural dressing does not allow fungus spores to germinate or the hyphæ to develop after germination. Now, white fir is distinctly poor in resin. Large superficial wounds may therefore prove to be more serious. If the bark is destroyed, the cambium is killed and the sapwood dries out and cracks. Through these cracks air gains access to the interior of the tree and must in some way alter the chemistry and physics of the heartwood. The spores of heartwood-destroying fungi lodge in the cracks and upon germination may find a well-prepared substratum in the heartwood. Fungi, like all plants, make certain specific demands as to the chemical composition, water content, oxygen, etc., of the substratum they live on. Given the proper temperature

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[1] Hartig, Robert. Lehrbuch der Pflanzenkrankheiten. Ed. 3, p. 153. Berlin, 1900

and the species of wood on which, for instance, a fungus like *Echinodontium tinctorium* (Indian-paint fungus), the most common destroyer of white-fir heartwood, can exist, its growth will still be dependent on the presence of heartwood of a certain character and on the water content of the heartwood. This is evidenced by the fact that decay is so commonly found in concentric development at a certain distance from the sapwood. The heartwood contains water in varying degrees, although it does not lift water like sapwood. But there is nothing surprising or irrational about the assumption that the water content of the heartwood will depend more or less on the water movement in the sapwood. The water in the heartwood of conifers is found in the membranes of the tracheids, not in the lumina. In a normal sound tree, heartwood of a given age and diameter surrounded by sapwood of normal width, corresponding to a certain crown development, will contain approximately a standard amount of water. Decrease in crown activity through some cause or another (suppression, injury to the crown, etc.) will soon be expressed in a rapid progress of heartwood formation, leaving only a narrow strip of sapwood, through which very much less water will move upward to the crown than in the normal tree. We may safely assume that the water content of the heartwood will change to a certain degree with the amount of water moved upward in the sapwood. The water content of the sapwood changes, furthermore, with age, and also with the season. Both changes must also appear, although in a far less degree, in the heartwood. Münch[1] has emphasized, in a series of very interesting papers, the relation of wood-inhabiting fungi to the water and air content of the host tissues. Water-logged tissues are inaccessible to these fungi; a certain minimum of air, as Münch expresses it, must be present in the tissue in order to allow the development of the hyphæ.

Variations in the water contained by imbibition in the cell membranes must influence the degree of humidity of the air in the lumen of the cell itself; it is quite probable that this factor also plays a rôle in the distribution of hyphæ in the wood.

What percentage of water in the cell membranes and of air in the lumina of the heartwood presents the optimum for the development of *Echinodontium tinctorium* and other similar fungi we do not know; but evidently there must be an optimum, a maximum, and a minimum. Any factor influencing the quota of water and air in the heartwood must, therefore, be of great importance. Cracks in the sapwood

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[1] Münch, Ernst. Die Blaufäule des Nadelholzes. *In* Naturw. Ztschr. Land- u. Forstw., Jahrg. 5, 1907, Heft 11, pp. 531–573; Jahrg. 6, 1908, Heft. 1, pp. 32–47, 33 figs.; Heft. 6, pp. 297–323.

Münch, Ernst. Untersuchungen über Immunität und Krankheitsempfänglichkeit der Holzpflanzen. *In* Naturw. Ztschr. Forst- Land u. w., Jahrg. 7, 1909, Heft 1, pp. 54–75, 5 figs.; Heft 2, pp. 87–114; Heft 3, pp. 129–160.

Münch, Ernst. Über krankhafte Kernbildung. *In* Naturw. Ztschr. Forst- u. Landw., Jahrg. 8, 1910, Heft 11, pp. 533–547; Heft 12, pp. 553–569, 2 figs.

reaching to the heartwood admit air, and by evaporation change the water content of the heartwood; by oxidation, changes in its chemistry probably also take place.

The change must necessarily be intensified, the more serious the injury. Wounds exposing the heartwood heal over very slowly, and the heartwood which receives all its water from the sapwood must be modified very markedly in its chemistry and physics, particularly in its water and oxygen content, by the long exposure to the air. Moreover, from the time the injury happened until the time the wound is completely healed the heartwood is directly exposed to inoculation from spores of wood-destroying fungi adapted to white fir. Although the production of spores by a sporophore is enormous, by far the greater number are carried by air currents to places where they can not germinate for lack of moisture; many are intercepted by the natural screen ("forest screen") formed by the foliage and trunks of uninjured trees or by trees to which they are not adapted, and only a very small number finally land in the cracks of exposed sapwood or on exposed heartwood of white fir of the proper age. Of these, again, a very small percentage find temperature and moisture favorable for germination. This explains the fact that so many trees, although badly wounded, are not infected. But it stands to reason that every year during which the heartwood remains exposed adds to the danger of the tree becoming infected.

By far the deepest wounds are caused by fire. Although in white fir the danger in repeated fires feeding on the pitch flow following a first injury is comparatively slight, and although the lack of resin in the wood does not favor the hollowing out of the interior of the tree as it does in yellow pine, fire frequently causes very long wounds, which reach into the heartwood.

Spores can gain entrance to the heartwood through open frost cracks. Low temperatures and sudden drops of temperature are common throughout the range of white fir. Inside of the range they are more or less confined to certain localities and zones.

Lightning in white fir generally causes more or less superficial wounds. The peculiar injuries to be traced to lightning in white fir present many interesting features. Here we are only interested in injury which might lead to the infection of the heartwood. As in yellow pine, lightning sometimes tears long strips of bark off the tree and leaves the cambium and sapwood unprotected. In such cases both die and dry out, with the result that cracks in the sapwood lead into the interior of the tree. Smaller superficial lightning wounds locally kill the sapwood, which is very commonly attacked by secondary fungi, which do not do very serious damage. However, logs with lightning injury of this kind are liable to be thrown out as culls, although they generally contain some sound heartwood.

Other causes of serious wounds are comparatively rare. Occasionally a falling tree will brush off part of the bark of its neighbor. If the wound is large, the exposed sapwood dries out, cracks, and the heartwood becomes exposed. Very rarely a living tree shows signs of early girdling by rodents. Girdled trees as a rule are killed within a short time.

With very few exceptions the entrance of the fungus into the tree can be traced to one or more of the wounds just discussed. Occasionally, however, a tree showing no wounding at all is found to be decayed. In such cases the only means of entrance for the wood-destroying organism is through knots.

White fir prunes itself very poorly; the wood of the twigs is tough, hard, and resistant, and the branches do not break off very readily. Later, dead twigs may break off; in the cracks of the wood of the stubs spores of fungi may find proper conditions for germination and, once established, use the pin knot as a bridge from the exterior of the tree through the bark and sapwood into the heartwood. This is particularly true for twigs in which heartwood formation has begun. In this sense the opening afforded to fungi by a pin knot that is not healed over may be likened to a wound. The opening formed by the pin knot, however, is too small to materially influence the chemistry and physics of the heartwood of the tree.

White fir is not exposed to a great number of heart-rot fungi. *Polyporus schweinitzii* is not common. *Polyporus sulphureus* and *Trametes pini* are rather rare. The parasitism of *Fomes pinicola* is not fully established, at least not in white fir. The writer has found it on thrifty sugar pine in central California, where it was undoubtedly parasitic in the sense of attacking the sound heartwood of living trees through an open fire scar and extending toward the sapwood. There would be no incongruity in assuming that it may also occur parasitically on white fir; in fact, a number of observations rather speak for the correctness of this assumption.

By far the most serious danger to white fir throughout its range comes from *Echinodontium tinctorium* Ellis and Ev. This fungus seems to be particularly adapted to *Abies concolor* and does not appear on many other species. In California it is, though not very often, found on *Abies magnifica shastensis* and also rarely on Douglas fir. This fungus must therefore be considered as the chief fungus enemy of white fir. The sporophores are easily recognized. They are rather large, from 2 to 10, 12, and more inches in width (measured horizontally from side to side where they are attached to the tree), distinctly hoof shaped, with a black, dull, cracked, rough upper surface, and a lighter, grayish, level under surface, which is thickly set with hard, coarse spines. In young specimens the under surface is whitish and rather dædaloid prior to breaking up into spines. The interior of the sporophore is vividly rusty red. This rusty color is most characteristic of the fungus and repeats itself very often in the decayed tissues of the host. The sporophores are never formed on the bark of the tree; invariably they appear from the under side of stubs of dead twigs or branches, and commonly the rusty color can be followed through these stubs or knots. As the sporophore is nothing but the fruiting body of the mature fungus plant living in the heartwood of the tree, which alone it is able to attack, every sporophore is a certain sign of far-reaching decay in the tree. The typical rot may be characterized as a stringy brown rot. Wood in this stage of decomposition is brown, with rusty reddish streaks, and becomes distinctly fibrous and stringy. Following the rot away from its maximum of development, we find wood still brown, with rusty streaks, but quite firm. Farther away, the brown color becomes less noticeable, the rusty color disappears, and finally we come to a point where the wood seems to be sound enough to be sent to the mill. A little care exercised in examination, however, will show in this seemingly sound wood the presence of small light-brownish spots and discolorations, particularly in the summer wood, intermingled with horizontal burrows, which at first glance could almost be taken for very shallow insect burrows. The burrows are not easily detected on a cross section. The small brown spots, which give the wood a faintly brown, mottled appearance, cause the entire cross section to be slightly darker than normal and discolored; but they show up very much more clearly in a longitudinal section. A small piece pried out of the end of the log with a hatchet or strong knife gives sufficient information about the real state of health of the log. This timber at present invariably goes to the mill and without doubt furnishes the lumber that, after being sawed, dries out and by becoming brittle causes the well-known prejudice against this species. It is often characterized by a peculiar sour smell and by a spongy consistency of the wood.

Cull from decay in white fir, therefore, includes not only typical rot but also this discolored material, which, although not distinctly rotten, is already under the influence of the advance guard of the fungus mycelium and will become completely decayed later on. For this stage of incipient, or, better, latent decay, the writer proposes the term "advance rot," which is used throughout this bulletin.

DESCRIPTION OF AREAS.

The three areas chosen for investigation are located on the Crater National Forest, in southwestern Oregon, all of them in the neighborhood of the Upper Klamath Lake, a large shallow basin with vast swamps, into which unusually large springs of clear cold water empty themselves. Very few streams of running water come from the surrounding mountains. Dense timber frames the swamps and extends up the slopes to the mountain tops. The elevation of all three tracts varies from 4,150 to about 4,400 feet. Low winter temperatures and severe lightning storms are frequent in the entire region. Two of the tracts, the Pelican Bay Lumber Co. sales area and the Odessa ranger-station tract, are situated on the west shore of the lake. They are about 2 miles apart and present conditions so much the same that they can be considered as one.

The Pelican Bay tract on the west side of Pelican Bay lies, as far as the area covered by this study is concerned, along the slopes; the aspect is east to northeast. That is, it is exposed to cold wintry winds, sweeping unbroken across Upper Klamath Lake. We may expect frost injury. The volcanic soil is fairly deep and loose; the humus layer is rather shallow. There are no rock outcrops. The underbrush is composed of Ceanothus, manzanita, and some chinquapin.

The Odessa ranger-station tract is far less steep than the Pelican Bay tract. A considerable part of it is a gentle slope, almost level. The general aspect is north; presumably the tract is less exposed to sweeping winds of very low temperature. The soil is decomposed lava, but richer in humus than the Pelican Bay tract. Outcrops of rock are frequent. There are a number of large springs in the neighborhood. The underbrush is rather dense and is composed of *Amelanchier alnifolia*, *Ceanothus velutinus*, with some *Salix* sp.; the ground cover consists of *Ceanothus prostratus*, *Berberis aquifolium*, and *Symphoricarpus racemosa*.

The third tract, the Otter & Burns sales area, lies about 15 miles north of the north end of Upper Klamath Lake. The tract is level, the soil very loose, sandy, decomposed pumice, with no indication of rock. Under the influence of the Fort Klamath Valley with its swamps, the atmospheric humidity is rather high, as is evidenced by the rich lichen flora, *Alectoria fremontii* being common. Thus the immediate surface of the soil is kept damp, and litter disintegrates very rapidly. The humus is about 1 to 2 inches deep; the soil immediately underlying it is remarkably well drained. The rapid humification in the top layers favors the development of mycorrhiza on the roots of white fir in surface strata. White fir seedlings show a thick matting of mycorrhiza, confined to the same strata of a certain humification, and a very long taproot seeking water. Yellow-pine seedlings also develop a taproot, but the mycorrhiza rootlets are found at a greater depth than those of white fir. They are not as closely bunched as in white fir and are distributed over a larger area in a vertical direction. The underbrush is formed by *Ceanothus velutinus* of medium density, from 4 to 6 feet high, in a uniform cover.

On the two tracts near the lake white fir is mixed with yellow pine and Douglas fir, a little incense cedar, and a very little sugar pine. On the Otter & Burns tract the stand is composed of yellow pine and white fir, with occasional lodgepole pine.

On each tract conditions were more or less uniform, differences in elevation were negligible, and neither deep gulches nor steep slopes had to be figured with as disturbing factors. All in all, 160 trees were dissected and notes taken on all factors which possibly would have some bearing on the subject of this bulletin. In operating, the tracts were not clean cut; that is, not every white-fir tree in the area was felled and examined, since it was not the object of the study to establish a cull per cent for that particular region.

The data obtained are from selected trees. On the Pelican Bay Lumber Company's sales areas the trees, of course, had all been marked by the Forest Service officers in charge; on the Otter & Burns sales area some trees were marked, and others were felled independently of marking. On the Odessa ranger-station tract all trees examined were felled for our special purpose. The representation of trees of different ages, diameter, and height classes on the three tracts, therefore, is not expressed correctly by the number of trees examined on each tract.

LOCAL PATHOLOGY OF WHITE FIR.

The pathology of white fir in the Upper Klamath Lake region is comparatively simple. Of injurious factors of an inanimate nature, fire, lightning, and frost are common.

Very few species of fungi inhabiting living white fir are found on the three tracts. As we are mainly interested in the pathology of the the wood, the occasional occurrence of *Peridermium elatinum* and of *Lophodermium nervisequium* becomes an entirely negligible factor.

Of heartwood-destroying fungi in living white fir, *Echinodontium tinctorium* is by far the most common, and sporophores are numerous. About 75 per cent of all cases of decay were due to this fungus. Occasionally decay may with some certainty be traced to *Fomes pinicola.* In one case a sporophore of an Irpex was found in the decayed hollow of the trunk. *Trametes pini* is missing altogether, though found occasionally on neighboring sugar pine. Decay caused by *Polyporus schweinitzii* was found in several cases, never with sporophores.

In other cases the decay was too indefinite to allow an identification of the fungus causing it. This is particularly true for the many cases of localized advance rot connected with scars from diffused lightning.

The preponderance of *Echinodontium tinctorium*, especially in connection with really damaging decay, is so marked that in this study all important cases of decay are considered to be caused by this fungus.

A study of the fungi destroying down timber lies beyond the scope of this bulletin. The only practical aspect of their activity lies in the fact that down timber, limbs, branches, twigs, and needles are decomposed very rapidly.

It is evident that all the points discussed in the preceding pages must be kept in mind in taking field notes. But this is not sufficient. Work of this kind has very much the character of an exploration; surprises and discoveries are possible at any point of the road, and it is therefore indispensable constantly to be on guard in order not to overlook any phenomenon worthy of observation.

TABULATION OF DATA.

The next step is proper tabulation of the data obtained. The three tracts were so close together and conditions so similar that they were considered as one, and all notes were combined. Separate interpretation of the notes of each tract showed differences only in detail. The procedure was as follows:

A first table was compiled from the field notes giving all important data as well as all such data which might have a bearing on the subject of this bulletin. As we are particularly interested in the problem of the relation of age to infection and subsequent decay, a second table gave the same notes arranged progressively by the ages of the trees examined. This table formed the basis for further operations.

The youngest tree dissected was 60 years old, and it is the first to show decay (Table I). The possible age limit of infection is therefore at least 60 years; it is probably lower. But in practical forestry we do not seek an answer to the question of the earliest age at which a tree might become infected, interesting as this is from a mycological point of view, but, rather, from what age may we with reasonable certainty assume that serious decay becomes so prevalent as to distinctly impair the merchantability of the timber.

The tree in question has a diameter breast high of 10.1 inches; it is 44 feet high. A healed-over broad scar still visible externally at 2 to 8 feet above ground corresponds to an internal scar, reaching from 2 to 10 feet, and was probably caused by lightning. The injury happened 22 years ago and was distinctly superficial; the deterioration, in the form of a slight discoloration of the sapwood, follows this scar only, without extending any farther into the wood. This superficial damage does not render the affected logs unmerchantable. For practical purposes, therefore, such cases may be disregarded; they are negligible. In the interpretation of our material, the character and the degree of the damage must be considered with special relation to their bearing on the merchantability of the lumber. Not only the extent in longitudinal direction but also the distribution of the decay over the cross section enter into the valuation of this factor. In the present study, the lateral extent of decay, the distribution over the cross section, was estimated, as it is in practical scaling. Actual measurements are difficult to take, on account of the immense variability of the decay. In Table I, decay which neither in lateral extent nor in degree was considered sufficient to seriously injure the merchantability of the part affected was marked as negligible. The longitudinal decay was taken in linear feet, and the entire length was considered as affected, in order not to complicate the computation too much. We must distinguish between superficial decay of the sapwood and the more serious decay of the heartwood. Figures of superficial decay of sapwood are given in brackets (Table I, column 5).

The next trees are sound. A negligible decay occurs in a tree 73 years old. Its diameter breast high is 11.2 inches; its height 58 feet. The light decay started from an internal scar, caused by fire 23 years ago and healed over in 5 years, but it remained in close proximity to the scar without spreading. Again, a number of sound trees follow. Then the first more serious decay appears.

The tree in question is 84 years old, its diameter breast high only 8 inches, height only 45 feet. Both fire and lightning have played havoc with this individual. An open scar extends from the ground 21 feet up the bole. The tree is quite evidently not in good health, the sapwood is very narrow, and the crown is lopsided and very short. Even in this case the decay follows more or less the open scar, but it is sufficiently serious to cull the affected parts in so small a tree; in a larger and thriftier one the damage would be called more or less local and a nominal deduction made in the scale. From a lumbering point of view this tree may be disregarded.

So far, all trees considered had been either thrifty or not very seriously wounded. Here we have an obviously suppressed, unhealthy, and badly wounded tree; it presents at the same time the first case of decay that is not to be called negligible. The following trees are sound; then follows a negligible trace of decay in an 86-year-old tree, badly suppressed (diameter breast high 4 inches, height 13 feet), grown in dense shade, with a remarkably small crown and with a healed-over frost crack, but no other wounds. After several sound, fairly thrifty trees follows a tree 87 years old, badly suppressed (diameter breast high 7.8 inches, height 39 feet), with a very short crown, wounded badly by fire and lightning (open scar from ground to 18 feet), and with decay following more or less closely the open scar.

From these and the following trees, it appeared possible that with increasing age the crown class, or rather the degree of suppression and dominance, played a rôle with regard to the extent and seriousness of the decay. Preliminary studies on incense cedar had given the same indications. It seemed desirable, therefore, to express this degree of suppression and dominance by a figure which would allow direct comparison between trees of the same age. Height alone would be misleading. Volume table figures can not be used, since they are based on sound normal trees. The relation of height to diameter breast high, expressed in total volume, was thought to be a safer index. The object being to obtain directly comparable figures by ages and not the exact volume, the tree was considered as a perfect cone over the stump, at which we had taken the ages. From somewhat scanty, but individually reliable notes, the diameters at the stump (diameter outside bark 18 inches) were obtained, and from these and the height the volume of the cone in cubic feet was computed.

TABLE I.—*Fundamental data on the pathology of the white fir.*

No. of tree.	Age.	Volume (cubic feet).			Character of wounds.
		For each tree.	Average for trees of same age.	Of rot, including advance rot (percentage of total volume).	
1	2	3	4	5	6
136	60	11.3	15(?)	[1] [34.2]	Lightning.
105	69	25.1	19	—	Leader healed in.
145	71	11.8	20	—	No wounds.
135	72	18.8	20	—	Very slight lightning.
147	72	7.7	20	—	No wounds.
143	73	18.5	20.3	12.7	Fire; healed.
159	76	23.0	21	—	Lightning.
111	78	12.4	21.3	—	Very little lightning.
134	80	31.4	23	—	Do.
139	81	45.5	24	—	Several scars.
138	82	29.9	24.1	—	Lightning (?).
89	84	44.4	24.6	—	No wounds.
125	84	8.9	24.6	82.8	Fire, open; lightning.
130	84	25.6	24.6	—	Little lightning.
133	85	7.5	25	—	No wounds.
137	86	33.7	26	—	Little lightning.
144	86	6.3	26	Negligible.	Frost ridge.
146	86	22.8	26	—	No wounds.
148	87	13.3	26.5	—	Ligthning.
149	87	27.1	26.5	—	Very little lightning.
124	87	6.8	26.5	82	Lightning with fire.
129	87	9.6	26.5	—	Fire; healed.
88	90	30.1	29	19.9	Fire, healed; lightning.
90	92	128.1	30	—	No wounds.
128	92	10.2	30	—	Very little lightning.
103	94	44.8	31	—	Fire, open; lightning.
122	96	38.1	32.5	[4.53]	Fire, open.
127	96	32.9	32.5	—	No wounds.
76–a [2]	96	25.1	32.5	55.3	Fire, open.
76–b [2]	96	25.1	32.5	13.5	Lightning.
21	101	46.5	37	—	Do.
120	102	22.3	38	16.8	Fire, open.
132	103	34.2	39	61	Fire; lightning.
46	103	35.2	39	—	No wounds.
72–a	104	25.5	40	[2.39]	Lightning.
72–b	104	25.5	40	71.8	Do.
158	104	68.2	40	47.6	Old girdling; lightning.
126	105	20.7	41	43.5	Fire, open.
18	105	90.3	41	—	No wounds.
20	105	32.2	41	—	Do.
45	105	58	41	—	Do.
87	105	52	41	—	Do.
102	106	29	42	46.9	Fire, open.
121	106	48.3	42	Traces.	Lightning.
68	107	17.0	43	45.5	Falling tree.

[1] The use of brackets ([ ]) in column 5 indicates superficial decay of sapwood.
[2] The letters a and b indicate two distinct foci of decay in the same tree.

TABLE I.—*Fundamental data on the pathology of the white fir*—Continued.

No. of tree.	Age.	Volume (cubic feet).			Character of wounds.
		For each tree.	Average for trees of same age.	Of rot, including advance rot (percentage of total volume).	
1	2	3	4	5	6
80	107	40.6	43	[92.2]	Lightning.
123	107	39.6	43	—	Little lightning.
19	107	65	43	—	No wounds.
44	107	55.0	43	[9.12]	Frost crack.
23	108	61.2	44	—	No wounds.
62	109	33.8	45	—	Do.
100	110	30.0	46	68.5	Fire, open.
22	110	47.7	46	—	No wounds.
75	110	14.7	46	—	Fire, open.
78	110	72.6	46	58.7	Do.
108	110	24.8	46	—	Little lightning.
110	110	26.8	46	—	Very little lightning.
104	111	32.1	47	23.7	Fire, open.
131	111	14.6	47	—	Fire; little lightning.
94	112	66.2	48	42.9	Twin healed in; frost crack.
99	112	40.8	48	42.1	Fire, open; lightning.
37	112	40.7	48	51.5	Frost crack.
96	113	25.7	49	[23.9]	Fire, open.
101	114	30.3	50	—	Fire; lightning.
97	116	11.7	52	[Trace.]	Fire, open.
109	116	36.3	52	40	Do.
98	118	11.5	53.5	—	No wounds.
140	118	20.5	53.5	—	(?)
40	119	89.5	54	—	Fire.
74	119	37.6	54	100	Fire; lightning.
115	121	18.9	56	—	Lightning.
150	122	46.3	57	—	Little lightning.
58	123	39.5	58	89.0	Frost crack.
69	123	18.5	58	[8.8]	Lightning.
154	123	21.8	58	77	Fire, open.
38	124	141	59	29.0	Fire.
56	124	21.3	59	60.0	Frost crack; lightning.
113	124	30.5	59	Negligible.	Fire, open; lightning.
33	125	53.5	61	—	Lightning.
41	125	125.5	61	58.1	Fire, open.
60	126	42.7	62	82.1	Frost crack.
79	129	85.6	65	80.3	Fire, open; frost crack.
54	130	32.8	66	77.5	Lightning.
63	130	52.3	66	32.4	Fire, open.
65	131	14.3	67	93.7	Frost crack.
17	132	87.4	69	—	No wounds.
30	132	256.5	69	—	Do.
49	132	98.2	69	65.3	Frost crack.
42	133	90.2	70	34.6	Fire, open.
112	133	26.4	70	—	Lightning.
53	134	28.8	71	21.8	Do.
28	135	55.1	73	42.0	No wounds.
55	135	83.2	73	60.7	Fire; frost cracks; lightning.
26	136	9.9	74	95.6	Frost crack.
16	136	108	74	—	No wounds.
48	136	86.4	74	76.9	Do.
1	137	49.1	76	—	Do.
50	137	33.6	76	85.3	Lightning.
2	138	77.4	78	—	Do.
15	138	76.3	78	—	Frost crack.
6	140	54.4	80	96.4	Fire.
7	140	187.0	80	—	No wounds.
70	140	20.6	80	132.7	Lightning.
119	140	24.3	80	100	Lightning, severe.
153	140	50.4	80	—	Lightning.
155	140	28.2	80	00	Fire, open; lightning.
43	140	136.5	80	133.5	Fire, open.
156	141	51.1	82	00	Do.
61	143	35.0	86	51.2	Falling tree; frost crack; lightning.
11	144	235.5	87	—	No wounds.
4	146	94.5	90	[27.7	Fire.
106	146	30.0	90	88]	Frost crack; lightning.
5	148	135.5	94	70	Frost crack.
35	148	154	94	—	No wounds.
92	149	34.1	96	60.1	Fire, open.
10	150	66.5	97	—	No wounds.

TABLE I.—*Fundamental data on the pathology of the white fir*—Continued.

No. of tree.	Age.	Volume (cubic feet).			Character of wounds.
		For each tree.	Average for trees of same age.	Of rot, including advance rot (percentage of total volume).	
1	2	3	4	5	6
25	150	123.5	97	81.5	Frost crack.
114	150	45.6	97	55.5	Fire, open; lightning.
157	150	112.5	97	68	Do.
151	151	16.6	99	41.3	(?)
85	152	192.5	101	58.1	Frost crack.
9	152	75	101	15.7	Do.
13	155	235	107	63.2	Fire, open.
31	155	121	107	36.2	Do.
117	155	37.7	107	Negligible.	Lightning.
83	156	380	109	36.5	Fire; frost crack.
91	156	96.5	109	32.8	Do.
27	159	152.0	109	—	No wounds.
12	160	224.5	116	73.7	Fire, open.
93	160	26.8	116	98.5	Fire, open; lightning.
118	161	68.6	118	—	Lightning.
160	161	68.2	118	89.4	Frost crack.
116	162	38	121	—	Lightning.
47	163	122.5	123	—	Notes missing.
81	163	106	123	82.9	Fire, open.
84	164	417	125	25.5	Frost crack (healed); lightning.
3	165	(?)	127	Incomplete.	Fire, open.
51	165	128.5	127	53.4	Fire; lightning.
24	166	57.2	129	(?)	Notes missing.
32	166	171.5	129	—	No wounds.
29	168	179	134	—	Fire.
82	169	291.7	136	6.8	Fire; frost cracks.
8	170	328.5	138	53	Fire.
57	170	121	138	87.4	Frost crack.
67	170	123.8	138	67.2	No wounds.
64-a	175	68.0	150	47.1	Fire, open.
64-b	175	68.0	150	16.4	Lightning.
36	178	212.7	158	—	Frost crack.
52	178	127.7	158	[5.1]	Lightning.
77	180	133	164	16.7	Fire, open.
71	183	100	[166]	39.5	Lightning.
34	185	148.3	[166]	—	No wounds.
95	185	100.5	[166]	53.6	Fire, open.
107	186	42.85	[166]	—	Lightning.
66	189	64.4	[168]	—	Frost ridge; lightning.
39	191	546	[168]	52	Fire.
86	192	110.7	[170]	95.5	Fire, open; frost cracks.
14	200	115.7	[180]	Negligible.	Frost crack.
142	200	26.0	[180]	100	Fire, open; lightning.
73	221	196	[190]	100	Frost crack; lightning.
59	232	235	[200]	71.3	Lightning.
141	258	46.7	[220]	[100]	Fire, open; frost cracks; lightning.

These volumes are, of course, not directly comparable with each other; they have a meaning only when individually compared with normal volumes for the same age. It was necessary, therefore, to curve data collected on normal trees, such as were selected for volume tables in larger numbers on the same area. The most reliable portion of this curve lies between 80 and 180 years. The relation of the actual to the average volume of trees of the same age we may use as an index of suppression or dominance of the individuals in question.

The volume of the decayed part of the bole was figured as the affected part of the cone. But instead of giving the decay simply in cubic feet, making constant reference to the total volume of the tree necessary, the volume of the rot was expressed in percentage of the total volume. Advance rot—that part of the wood already under the influence of the mycelium—is included. It must be kept in mind that all figures given under this heading (column 5) are therefore likely to be high. To be on the conservative side, all measures of decay were taken very carefully, and in all cases where there was any possible doubt the uncertain part was measured as decay. But since the same procedure was followed consistently the results are directly comparable.

Table I gives us our working material in figures. Column 1 shows the individual number of each tree from the field notes and is given only for convenience of reference, the trees being arranged in the order of their ages (column 2). Column 3 shows the actual or total volume in cubic feet of each tree, considered as a perfect cone. Column 4 gives the volume in cubic feet for the average tree of the same age. Column 5 shows the volume of rot (including advance rot) in cubic feet expressed as a percentage of the total volume of the tree. Column 6 shows the character of the wounds.

CONDENSATION OF DATA.

It proved difficult to interpret intelligently this mass of figures. If there existed any relation between decay and possible influencing factors, it certainly did not appear very clearly from this table. It became necessary to simplify and condense the material.

Instead of expressing dominance or suppression by the relation of the actual to the normal volume in figures, the system of crosses described above for the field notes was used. Three classes were adopted—dominant, intermediate, and suppressed. Those volumes which came closest to the average were considered intermediate and entered in the table with one cross, which expresses the affirmative; a dash signifies negation. In the intermediate class therefore there can be not more than one cross. The deviation from this average shows in the two other classes, and as here all degrees are possible, the degree of suppression or of dominance is shown with one, two, or three crosses. Thus, three crosses under "Dominance" mean that the tree is as far beyond the average as is possible in that locality. On the other hand, one cross under "Suppression" means that the tree is decidedly suppressed, two crosses that it is badly suppressed, and three crosses indicate the highest degree of suppression. This classification is admittedly arbitrary; it seemed to answer the purpose, however, and has so many advantages, with its possible grades and its graphical clearness, that it may be retained until some better method is devised. (Table II, columns 3, 4, and 5.)

To reduce the figures in column 5 of Table I to simpler symbols was more difficult. Here the entire affected part of the cone for practical purposes was considered as cull, including the sapwood. In reality, there are, of course, all gradations from a slight discoloration of the sapwood following a long lightning scar or a number of smaller scars to complete destruction of the heartwood by decay. In order to simplify this column and to bring out more forcibly its relation to influencing factors, the writer tried to reduce the percentage figures to ratings, applying the system of crosses used throughout this study, taking into account not only the volume percentage of rot in cubic feet, but also the character of the injury with regard to the degree of rottenness. Thus, one cross in parentheses, (x), signifies slight and negligible local discoloration; one cross (not in parentheses) shows distinct rot, but affecting not more than about one-third of the tree; two crosses, about two-thirds of tree affected; three crosses, more or less of the entire tree affected. In each case, the character of the decay as indicated by the detailed field notes was given due consideration. This explains apparent discrepancies between decay rating and decay volume in the percentages in Table I, where the affected part of the bole was considered as cull for the entire length of the decay. In decay rating, the actual loss in merchantability was expressed according to the character of the rot and its extent. This valuation of the decay, it is true, is necessarily somewhat arbitrary. It is really the condensation of carefully taken field notes and measurements and must serve until a more satisfactory method can be found. Where general relationships only are concerned, as in this case, our symbols may be sufficiently correct, provided they are based on exact figures and reliable field notes. (Table II, column 6.)

In order to insure a higher degree of reliability for the decay-rating symbols, the operation was repeated some time later without consulting the results of the first. With insignificant exceptions, both ratings were identical.

In much the same way the character and degree of wounding was reduced to a system of crosses. Plainly, this can be done only from field notes, which were generally amplified by actual measurements of the size and extent of the wound. The chances of inoculation offered by a wound decide its rating. That deep wounds, particularly such as have remained open for a longer time, are rated higher than small superficial injuries, soon healed over, is self-evident. The system of crosses is the same as heretofore explained. (Table II, column 7.)

The next column (Table II, column 8) indicates the means whereby the fungus entered the tree, as evidenced by the analysis.

TABLE II.—*Condensed data on the pathology of the white fir.*

No. of tree.	Age.	Degree of dominance or of suppression.			Decay rating.	Wound rating.	Infection traced to—	Apparent condition of crown.	Remarks.
		Dominance.	Intermediate.	Suppression.					
1	2	3	4	5	6	7	8	9	10
136	60	—	—	x	—	xx	Lightning	(x)	Negligible; advance rot.
105	69	xx	—	—	....	(x)	—	(x)	
145	71	—	—	xx	....	—	—	(x)	
135	72	—	—	x	....	—	—	(x)	
147	72	—	—	xx	....	—	—	(x)	
143	73	—	—	x	—	xx	Fire	(x)	Negligible.
159	76	—	x	—	....	x	—	x	
111	78	—	—	xx	....	—	—	x	
134	80	xx	—	—	....	—	—	(x)	
139	81	xxx	—	—	....	xx	—	(x)	
138	82	xx	—	—	....	x	—	(x)	
89	84	xxx	—	—	....	—	—	x	
125	84	—	—	xxx	xx	xxx	Fire; lightning.	xxx	
130	84	—	x	—	....	—	—	(x)	
133	85	—	—	xxx	....	—	—	x	
137	86	x	—	—	....	x	—	(x)	
144	86	—	—	xxx	—	xx	Frost crack	xxx	
146	86	—	—	x	....	—	—	(x)	
148	87	—	—	xx	....	xx	—	(x)	
149	87	—	x	—	....	—	—	(x)	
124	87	—	—	xxx	x	xxx	Lightning; fire.	xxx	
129	87	—	—	xxx	....	x	—	x	
88	90	—	x	—	x	xx	Fire	x	Advance rot.
90	92	xxx	—	—	....	—	—	x	
128	92	—	—	xx	....	—	—	(x)	
103	94	x	—	—	....	xx	—	x	
122	96	x	—	—	—	xx	Fire, open	x	Negligible.
127	96	—	x	—	....	—	—	x	
76-a	96	—	—	xx	xx	xxx	Fire, open	x	Advance rot.
76-b	96	—	—	xx	x	xxx	Lightning	x	Do.
21	101	xx	—	—	....	xx	—	x	
120	102	—	—	xx	—	xxx	Fire, open	x	Advance rot.
132	103	—	—	x	xx	xxx	Fire	(x)	Open 22 years.
46	103	—	—	x	....	—	—	x	
72-a	104	—	—	xx	—	xxx	Lightning	xx	Advance rot.
72-b	104	—	—	xx	x	xxx	do	xx	Do.
158	104	xx	—	—	xx	xxx	Girdling	(x)	Almost completely girdled 82 years ago; wound open 31 years; mostly advance rot.
126	105	—	—	xx	xx	xxx	Fire, open	x	
18	105	xxx	—	—	....	—	—	x	
20	105	—	—	xx	....	—	—	x	
45	105	x	—	—	....	—	—	x	
87	105	x	—	—	....	—	—	x	
102	106	—	—	xxx	xx	xxx	Fire, open	xx	
121	106	—	x	—	—	xxx	Lightning	x	Negligible.
68	107	—	—	xxx	x	xxx	Falling tree	xx	Advance rot.
80	107	—	x	—	x	xx	Lightning	x	Advance rot localized in scars.
123	107	—	—	x	....	—	—	x	
19	107	xx	—	—	....	—	—	x	
44	107	xx	—	—	—	xx	Frost crack	(?)	Negligible.
23	108	xx	—	—	....	—	—	x	
62	109	—	—	x	....	—	—	x	
100	110	—	—	xx	x	xxx	Fire, open	x	Mostly advance rot.
22	110	—	x	—	....	—	—	x	
75	110	—	—	xxx	....	xx	—	x	
78	110	xx	—	—	xx	xxx	Fire, open	(x)	Rot following two very long open scars.
108	110	—	—	xxx	....	—	—	(x)	
110	110	—	—	xxx	....	—	—	(x)	
104	111	—	—	xx	x	xxx	Fire, open	x	Advance rot.
131	111	—	—	xxx	....	x	—	(x)	
94	112	x	—	—	x	xxx	Twin and frost crack.	x	Very slight advance rot.
99	112	—	—	x	x	xxx	Lightning	xx	Slight advance rot.
37	112	—	—	x	x	xxx	Frost crack	x	Do.
96	113	—	—	xx	—	xxx	Fire, open	x	Little typical rot.
101	114	—	—	xx	....	x	—	x	

TABLE II.—*Condensed data on the pathology of the white fir*—Continued.

No. of tree.	Age.	Degree of dominance or of suppression.			Decay rating.	Wound rating.	Infection traced to—	Apparent condition of crown.	Remarks.
		Dominance.	Intermediate.	Suppression.					
1	2	3	4	5	6	7	8	9	10
97	116	—	—	xxx	—	xx	Fire.............	x	Negligible.
109	116	—	—	xx	x	xx	Fire, open.......	x	Mostly advance rot.
98	118	—	—	xxx	....	—	—	x	
140	118	—	—	xxx	....	(x)	—	(x)	
40	119	xx	—	—	....	xx	—	x	
74	119	—	—	xx	x	xxx	Fire (?), with lightning.	x (?)	Advance rot.
115	121	—	—	xxx	....	x	—	x	
150	122	—	—	x	....	—	—	(x)	
58	123	—	—	xx	xx	xx	Frost crack.....	x	Much advance rot.
69	123	—	—	xxx	—	x	Lightning.......	x	Advance rot; negligible.
154	123	—	—	xxx	xx	xxx	Fire, open.......	x	Very long scar.
38	124	xxx	—	—	x	xx	Fire.............	x	Little advance rot.
56	124	—	—	xxx	x	xx	Frost crack.....	x	Advance rot.
113	124	—	—	xx	—	xx	Fire; lightning..	x	
33	125	—	—	x	....	x	—	x	
41	125	xxx	—	—	xx	xxx	Fire, open.......	x	Much advance rot.
60	126	—	—	xx	xxx	xx	Frost crack.....	x	Sporophore.
79	129	x	—	—	xxx	xxx	Fire, with frost crack.	x	Two very bad burns held open by frost crack for 85 years; sporophore.
54	130	—	—	xxx	xx	xxx	Lightning.......	x	Much advance rot; young sporophore.
63	130	—	—	xx	xx	xxx	Fire, open.......	xx	Very bad open fire scar.
65	131	—	—	xxx	xxx	xx	Frost crack.....	(?)	
17	132	xx	—	—	....	—	—	x	
30	132	xxx	—	—	....	—	—	x	
49	132	xx	—	—	xxx	xx	Frost crack.....	x	Much advance rot; 2 sporophores.
42	133	xx	—	—	x	xxx	Fire, open.......	x	Mostly advance rot.
112	133	—	—	xxx	....	xx	—	xx	
53	134	—	—	xxx	x	x	Twin (?)........	x	Advance rot.
28	135	—	—	xx	x	—	Knots...........	x	Slight advance rot.
55	135	x	—	—	xx	xxx	Fire, with frost crack.	x	Much advance rot.
26	136	—	—	xxx	xxx	xx	Frost crack.....	xxx	Sporophore.
16	136	xx	—	—	....	—	—	x	
48	136	—	x	—	xxx	—	Knots...........	x	Sporophore.
1	137	—	—	xx	....	—	—	x	
50	137	—	—	xxx	xxx	x	Lightning and knots.	x	Much advance rot.
2	138	—	x	—	....	xx	—	x (?)	
15	138	—	x	—	....	x	—	x	
6	140	—	—	xxx	xxx	xx	Fire.............	(?)	Sporophore.
7	140	xxx	—	—	....	—	—	x	
70	140	—	—	xxx	x	xxx	Lightning.......	x	Slight advance rot.
119	140	—	—	xxx	xxx	xxx	.....do.........	xxx	
153	140	—	—	xx	....	x	—	(x)	
155	140	—	—	xxx	xxx	xxx	Fire, open.......	xxx	
43	140	xx	—	—	x	xxx	.....do.........	x	Tree almost killed at age of 81 years; mostly advance rot.
156	141	—	—	xxx	xxx	xxx	.....do.........	x	
61	143	—	—	xxx	xx	xx	Frost crack; wounds from falling tree.	x	Much advance rot near wounds.
11	144	xxx	—	—	....	—	—	x	
4	146	—	x	—	x	xx	Fire.............	x	Advance rot.
106	146	—	—	xxx	xx	xxx	Lightning and frost.	x	Much advance rot in scars.
5	148	xx	—	—	xx	xx	Frost crack.....	x	Small sporophore.
35	148	xxx	—	—	....	—	—	x	
92	149	—	—	xxx	xx	xxx	Fire, open.......	xx	Rot following scars.
10	150	—	—	xx	....	—	—	x	
25	150	xx	—	—	xxx	xxx	Frost crack.....	x	
114	150	—	—	xxx	xx	xxx	Fire, open.....	x	
157	150	x	—	—	xx	xxx	.....do.........	xx	
151	151	—	—	xxx	xx	xx	(?)	xx	Much advance rot; small tree.

TABLE II.—*Condensed data on the pathology of the white fir*—Continued.

No. of tree.	Age.	Degree of dominance or of suppression.			Decay rating.	Wound rating.	Infection traced to—	Apparent condition of crown.	Remarks.
		Dominance.	Intermediate.	Suppression.					
1	2	3	4	5	6	7	8	9	10
85	152	xx	—	—	xx	x	Frost crack......	x	Two sporophores.
9	152	—	—	xx	x	xx	.....do..........	x	Scar long healed over.
13	155	—	—	xxx	xx	xxx	Fire, open.......	x	
31	155	x	—	—	x	xxx	Fire.............	x	Slight advance rot.
117	155	—	—	xxx	—	xx	Lightning........	xxx	
83	156	xxx	—	—	xx	xxx	Frost crack......	x	Much advance rot and shake.
91	156	—	—	x	x	xxx	Fire, open.......	xx	
27	159	xxx	—	—	....	—	—	x	
12	160	xxx	—	—	xxx	xxx	Fire.............	x	
93	160	—	—	xxx	xxx	xxx	Fire, open.......	x	
118	161	—	—	xxx	....	x	—	xxx	
160	161	—	—	xxx	xxx	xxx	Frost crack......	xxx	Sporophore.
116	162	—	—	xxx	....	x	—	x	
47	163	—	x	—	....	x	—	x	
81	163	—	—	x	xxx	xxx	Fire, open.......	xxx	
84	164	xxx	—	—	xx	xx	Knots............	x	Small sporophore.
3	165	(?)	(?)	(?)	xx	xxx	Fire.............	x	Notes incomplete; D. B. H. 26.5 inches.
51	165	—	x	—	xx	xx	.....do..........	x	Much advance rot.
24	166	—	—	xxx	x	(?)	(?)	x	Notes incomplete.
32	166	xx	—	—	....	—	—	x	
29	168	xx	—	—	....	(x)	—	x	
82	169	xxx	—	—	x	xxx	Knot.............	(x)	Very thrifty.
8	170	xxx	—	—	xx	xx	Fire.............	x(?)	
57	170	—	—	x	xxx	xx	Frost crack......	xx	Five sporophores.
67	170	—	—	x	xxx	—	Knot.............	x	Small sporophores.
64–a	175	—	—	xxx	xxx	xxx	Fire, open.......	x	
64–b	175	—	—	xxx	xx	xxx	Lightning........	x	Advance rot; small tree.
36	178	xx	—	—	....	x	—	x	
52	178	—	—	x	—	x	Lightning........	x	Advance rot.
77	180	—	—	xx	x	xxx	Fire.............	x	Advance rot and shake.
71	183	—	—	xx	x	xxx	Lightning........	xx	Advance rot.
34	185	—	—	x	....	—	—	x	
95	185	—	—	xx	xx	xxx	Fire, open.......	x	
107	186	—	—	xxx	....	xx	—	x	
66	189	—	—	xxx	....	xx	—	x	
39	191	xxx	—	—	xx	xxx	Fire.............	x	Fire 110 years ago.
86	192	—	—	xx	xxx	xxx	Frost crack......	x	Large sporophore.
14	200	—	—	xx	—	x	.....do..........	xxx	
142	200	—	—	xxx	xxx	xxx	Fire.............	xxx	Much advance rot; small tree.
73	221	—	x	—	xxx	xx	Frost crack with lightning.	xx	Four sporophores.
59	232	x	—	—	xxx	x	Lightning........	(?)	Much advance rot.
141	238	—	—	xxx	xxx	xxx	Fire with frost crack.	xxx	Mostly advance rot with shake.

Another column concerns the apparent condition of the tree (Table II, column 9) and indicates the appearance of health of the crown, taking the healthy, thrifty tree as normal (indicated by one cross) and marking the degree of deviation from the normal in the usual way. Thus, one cross in parentheses, (x), means that the tree is an exceptionally healthy one; two crosses (not in parentheses) indicate that the crown is rather poor, either in development or that the color is abnormal, etc.; and a tree having a very much underdeveloped and sickly looking crown is marked with three crosses. The personal factor may, of course, lead to misinterpretations unless the same standard is applied throughout the entire study. For this very reason it seemed doubtful from the beginning whether these data would be of much value. They are given here merely for the sake of completeness.

The condensed material was again tabulated. In the condensed table (Table II) the relation of decay to age can easily be followed by comparing columns 2 and 6. "Decay rating" is placed between "Suppression" and "Wound rating" in order to bring out forcibly any possible relation between these factors.

INTERPRETATION.

The column that interests us most is apparently the sixth, "Decay rating." In glancing over this column and comparing it with the neighboring ones we can read directly the connection of decay with factors that may be of influence. Each separate case of decay, of which one, two, or even more can occur on the same tree, may be called, for simplicity's sake, in this study, a "cull case." Each cull case is the result of a separate infection. The actual loss of timber by fire burning out the stump does not concern us here; cull from this source is included in the "volume of rot" whenever the decay is directly traceable to the fire wound. Otherwise the cull from fire is neglected. Cull from knots, limbs, or wind-shake is not considered. Altogether there are 97 cull cases.

The first two cull cases are negligible for practical purposes. Some loss occurs in tree No. 125, 84 years old. We see that this is a very badly suppressed tree, very seriously wounded, in very bad health, and that it is injured by both fire and lightning. Another case occurs in tree No. 124, age 87 years. Again suppression, wounding, and condition of health are marked with three crosses, indicating the worst possible conditions, together with two causes of wounds—fire and lightning. In both cases fire is the more serious, lightning often occurring higher up on the tree in numerous small wounds. It carries advance decay to the upper part of the bole and materially increases the volume-rot figure and the decay rating. The next cull case is a slight one (tree No. 88, age 90 years). The tree is intermediate, wound rating medium, health good, the decay only advance rot. Continuing down the "Decay-rating" column and comparing the symbols with those in the neighboring columns, we find that in almost every case the rating of rot more or less expresses or is explained by the factors of suppression and wound rating. Apparent discrepancies generally find their explanation under "Remarks" (column 10).

Suppression shows at an early age. A distinct preponderance of suppression is noticeable from about the age of 84 years. The first very pronounced cases appear in the same year. They seem to become particularly common from about 110 to 120 years.

Suppression stands out strongly as an important factor. Out of the total of 97 cull cases, 66 are connected with suppression. Considering that our average volumes over ages were curved from figures which were rather low and that the intermediate white firs in a virgin uneven-aged mixed stand are rather to be considered as recovering suppressed trees than as dominants decreasing in rate of height growth the intermediate class may consistently be added to the suppressed, giving 73 in all, or about 75 per cent. Suppression is commonly connected with a more or less high decay rating, provided the tree is wounded seriously. Again, low-volume trees with marked decay are more liable to be a total loss on account of their form. A rot volume percentage of 50, for instance, leaves still a good deal of merchantable stuff in a tree with high volume, but it would make a small tree completely unmerchantable. In the comparatively few cases where dominant trees show decay, the wounding is either of very momentous character or the decay is more or less insignificant and localized near the scars. This is true at least for the younger trees.

In glancing over the decay column we see that the higher ratings, xx and xxx, begin rather suddenly to become more frequent after the trees have reached the age of about 123 to 126 years; after the age of about 129 or 130 years they become very common. While decay in the broadest sense of the word may show in trees 60 years old and perhaps younger, the critical age of white fir with regard to more serious decay appears to lie at about 130 years, at least for the region investigated, taking into account that we have to deal here with a practically virgin stand grown up under the cumulative risk from suppression, frost, lightning, and the other factors of influence. Decay of any consequence appears at this age in trees with a combination of wounding and suppression. In the few apparent exceptions the decay is localized near unusually large wounds.

We find, further, that up to about 150 (148) years in badly wounded but dominant thrifty trees the decay is either not very far advanced in degree, if in extent, or that the wounding is of quite extraordinarily severe character.

Tree No. 49, age 132, seems to form an exception, but we will see later that frost cracks, though not offering a large opening by virtue of their length, are instrumental in the longitudinal advance of the decay. It seems that after about 150 years thriftiness as expressed by dominance is less able to outbalance the influence of serious wounding.

If it is at all permissible to draw any inference from the comparatively small amount of material at hand, we may distinguish three critical stages in the life history of wounded white-fir trees, and we must remember that by far the greater number of our trees, especially after they have reached the age of about 80 to 90 years, are wounded.

The first is the "age of infection," which may be at 60 years or below. Here the infection rarely leads to more than negligible decay unless the tree is handicapped by quite unusually severe conditions, such as very large old wounds.

The second, at about 130 years, which we may term the "critical age," marks the point after which a combination of pronounced suppression and heavy wounding generally results in distinct decay. This combination of deleterious factors is one commonly found in virgin forests. Wounding alone is not sufficient to unfavorably counteract thriftiness of growth.

Another change comes about at 150 years, when even dominant (that is, thrifty) trees become subject to extensive and intensive decay. We might term this the "age of decline," because the inability of the individual to throw off or keep in check the growth of the wound parasite in its heartwood indicates a distinct decrease in resistive powers, whatever their specific action may be, induced by age. For thrifty but wounded white fir, such as we may expect to raise under management, the age of decline is, therefore, the factor which will influence the rotation and cutting cycles of the species, since for many years to come the risk of inoculation will be more or less the same. There will be fires as long as there are lightning storms. Wounding through lightning and frost are inevitable. Besides, many trees are already wounded.

It is of interest to note that of a total of 160 trees only about 25 per cent did not show any wounds except very slight lightning scars. All the rest were wounded from some cause or other. Often a combination of fire, lightning, and frost cracks results in scarring a tree to such an extent that almost in every foot some blemish will be found. This is particularly true of the older trees which have been exposed to the cumulative risk of many years. Any of these wounds, if large enough, may offer an entrance to fungi. After the trees have reached the age of about 80 to 90 years, more than 70 per cent of them are already more or less badly wounded and therefore exposed to inoculation. After they are about 106 years of age more than 80 per cent are wounded.

In the remote future, when all these wounded trees are removed and when the risk of wounding for the trees growing up meantime is minimized, a new age of decline may be established. What this age of decline might be for unwounded white fir in managed forests we can not tell from our material, because of 97 cases of decay only 6 were not to be traced to some wounding. It is obviously out of the question to take even a clue from data of so scanty a nature. It may simply be mentioned that the first case of this kind appears at an age of 134 years in a suppressed tree. After all, it may be more than a coincidence that the first case of such infection in a suppressed tree occurs near the critical age for suppressed white firs in this region. It is within reason to assume that thrifty, uninjured white firs run only the evidently not very great risk of becoming infected through branch stubs. But decay entering through knots is always caused by fungi of a very aggressive character, such as *Echinodontium tinctorium*, which is not always the case with wounds. As a possible cause of infection we may also mention dead and broken-off leaders or volunteers, the stubs of which are only slowly overgrown.

It would appear that, if infections of unwounded trees are really so rare, white fir will take care of itself on the managed areas of the future. This would probably be the case in an ideal, 100 per cent normal forest. But this is utopian. There will always be a certain risk of wounding. Even after the already wounded individuals are eliminated, which will consume a number of decades, it is unreasonable to expect that our forests should then be so much closer to the normal than the best kept European forests are at the present day. How severe the loss from *Trametes pini* is in the Prussian forests has already been shown. Whatever may be the final verdict as to the age of decline of unwounded thrifty trees in managed forests, it can not be of more than purely theoretical interest to us and the next following generations. We must cope with present-day conditions as we find them, not as we would wish to have them.

The immense importance of fire in connection with decay appears so plainly from Table II that it is hardly necessary to emphasize the fact. The field notes show that in 59 trees wounded by fire, in only 11 was no decay traced to the fire wound. Fire, then, is one of the most important factors in connection with decay; all the more so, as fire generally attacks the butt part of the tree, and decay starting from fire wounds therefore destroys a much greater part of valuable timber than decay in the upper part of the bole.

Lightning generally results in comparatively light advance rot. From Table II it appears that the only tree in which serious decay could be traced to lightning, and in which it was neither connected with suppression nor with a serious wound from another source, is No. 59, 232 years old. To judge from our data, lightning is rarely connected with typical decay, although it often renders large parts of the tree partly unmerchantable.

The cumulative risk of wounding is shown in Table II (column 7) by the fact that the cases rated with three crosses become far more frequent after the trees have reached the age of about 90 to 100 years. After they have reached about that age such cases are commonly accompanied by decay. Serious decay follows serious wounding after about the age of 130 years (critical age) when combined with pronounced suppression, and without this it follows after the age of about 150 years is reached. The risk of wounding increases naturally with the age of the tree.

A number of wounded and badly suppressed trees escape infection, although they are far beyond the critical age. Not every wound must necessarily be inoculated. All such cases found are compiled in Table III.

TABLE III.—*Data on suppressed and wounded but not infected white-fir trees.*

Age.	Suppression rating.	Wound rating.	Character of wound.	Age.	Suppression rating.	Wound rating.	Character of wound.
87	xxx	x	Fire.	140	xx	x	Lightning.
110	xxx	xx	Do.	161	xxx	x	Do.
111	xxx	x	Do.	162	xxx	x	Do.
121	xxx	x	Lightning.	186	xxx	xx	Do.
133	xxx	xx	Do.	189	xxx	xx	Do.

In all cases but one in Table III the degree of suppression is very high; in this case the wound rating is low. The dangerous fire wounds in this table are confined to the youngest ages, 87 to 111 years; they were comparatively small in each case. The rest of the wounds are all due to lightning, which, as will be remembered, does not open up the interior of the tree unless very large parts of the bark are killed. For inoculation and infection, the character of the wound is all important. Suppression has nothing to do with inoculation; only after infection has taken place does its influence make itself felt.

The characteristics of each of the three ages, of course, hold good through the following ages. The combination of wounding with suppression, as shown in the critical age, for instance, must continue to favor decay in the age of decline.

Relative thriftiness (apparent condition of the tree) seems to have the least influence on the decay factor. It is really nothing but a statement of the present temporary appearance of the individual tree, which may be entirely different from what it was a few years ago or what it will be in the near future.

That far-reaching decay must not necessarily be reflected in the appearance and increment of the tree is shown, for instance, by trees Nos. 25 (age 150), 157 (age 150), 85 (age 152), 83 (age 156), and others in Table II. In all the trees mentioned, *Echinodontium tinctorium* had established itself and was vigorously growing. Tree No. 85 (age 152) even had two sporophores, and more than half the volume of the tree was decayed, indicating that the fungus must have lived in the tree for many years. The tree was apparently very thrifty; its volume, 192.5 cubic feet, as against 101, the average for its age (152 years). The increment was good. We can not, therefore, make *Echinodontium tinctorium* responsible for the decrease in thriftiness of infected white fir.

In order to further fix the relation between the character of the opening through which the fungus gains entrance into the wood and the character and extent of the decay, all cull cases were tabulated separately (Table IV).

TABLE IV.—*Cull cases of white fir, showing the extent of typical rot and its relation to the wound through which the infection took place.*

No.	Age.	Infection traced to—	Wounds.		Typical rot.		Remarks.
			Open.	Internal (healed over).	Confined to neighborhood of wounds.	Extending much beyond wounds.	
1	2	3	4	5	6	7	8
136	60	Lightning	—	x	x	—	Negligible.
143	73	Fire	—	x	x	—	
125	84	Fire with lightning	x	—	x	—	
144	86	Frost crack	—	x	x	—	Negligible.
124	87	Lightning with fire	x	—	x	—	Advance rot.
88	90	Fire	—	x	x	—	
122	96	do	x	—	x	—	
76a	96	do	x	—	—	(x)	
76b	96	Lightning	x	—	—	—	Advance rot.
120	102	Fire	x	—	x	—	
132	103	do	—	x	—	(x)	Remained open 22 years.
72a	104	Lightning	—	x	x	—	
72b	104	do	—	x	x	—	
158	104	Girdling	—	x	x	—	Almost completely girdled 82 years ago; open 31 years.
126	105	Fire	x	—	x	—	
102	106	do	x	—	x	—	
121	106	Lightning	x	x	x	—	Negligible.
68	107	Wound from falling tree.	x	—	x	—	
80	107	Lightning	—	x	x	—	
44	107	Frost crack	x	—	x	—	
100	110	Fire	x	—	x	—	
78	110	do	x	—	x	—	
104	111	do	x	—	x	—	
94	112	Twin and frost crack	—	x	x	—	
99	112	Lightning	—	x	x	—	
37	112	Frost crack	—	x	(?)	—	Frost.
96	113	Fire	x	—	x	—	
97	116	do	x	—	x	—	
109	116	do	x	—	x	—	
74a	119	Fire (?)	—	x	x	—	
74b	119	Lightning	x	—	x	—	
58	123	Frost crack	—	x	—	x	Frost.
69	123	Lightning	—	x	x	—	
154	123	Fire	x	—	x	—	
38	124	do	—	x	x	—	
56	124	Frost crack	x	—	—	—	Advance rot.
113	124	Fire with lightning	x	—	x	—	
41	125	Fire	x	—	x	—	
60	126	Frost crack	—	x	—	x	Frost.
79	129	Fire with frost crack	x	—	—	x	Do.
54	130	Lightning	—	x	x	—	
63	130	Fire	x	—	x	—	
65	131	Frost crack	—	x	—	x	Frost.
49	132	do	—	x	—	x	Do.
42	133	Fire	x	—	x	—	
53	134	Twin(?)	—	(?)	x	—	
28	135	Knots	—	—	—	x	Knots.
55	135	Fire with frost crack	—	x	—	x	Frost.
26	136	Frost crack	x	—	—	x	Do.
48	136	Knots	—	—	—	x	Knots(?).
50	137	Lightning and knots	—	x	—	x	Much advance rot.
6	140	Fire	(?)	(?)	—	x	Sporophore.
70	140	Lightning	—	x	x	—	
119	140	do	x	—	x	—	

TABLE IV.—*Cull cases of white fir, showing the extent of typical rot and its relation to the wound through which the infection took place*—Continued.

No.	Age.	Infection traced to—	Wounds.		Typical rot.		Remarks.
			Open.	Internal (healed over).	Confined to neighborhood of wounds.	Extending much beyond wounds.	
1	2	3	4	5	6	7	8
155	140	Fire	x	—	—	x	Condition very poor; suppression xxx.
43	140	.....do	x	—	x	—	
156	141	.....do	x	—	x	—	
61a	143	Frost crack	—	x	—	x	Frost.
61b	143	Falling tree	—	x	x	—	Advance rot.
4	146	Fire	(?)	(?)	(?)	(?)	Notes incomplete.
106	146	Lightning and frost	x	—	x	—	Advance rot.
5	148	Frost crack	—	x	—	x	Frost.
92	149	Fire	x	—	x	—	
25	150	Frost crack	x	—	—	x	Frost.
114	150	Fire	x	—	—	x	Butt open from fire 73 years ago; suppression xxx.
157	150	.....do	x	—	x	—	
151	151	(?)	—	x	x	—	
85	152	Frost crack	—	x	—	x	Frost.
9	152	.....do	—	x	x	—	
13	155	Fire	x	—	—	x	
31	155	.....do	x	—	x	—	
117	155	Lightning	—	x	x	—	
83	156	Frost crack	—	x	—	x	Frost.
91	156	Fire	x	—	x	—	
12	160	.....do	x	—	—	x	
93	160	.....do	x	—	—	x	Suppression xxx.
160	161	Frost crack	x	—	—	x	Frost.
81	163	Fire	x	—	—	x	Condition very poor; suppression x.
84	164	Knots	—	—	—	x	Knots.
3	165	Fire	x	—	—	x	
51	165	.....do	—	x	—	x	
24	166	(?)	(?)	(?)	(?)	(?)	Notes incomplete.
82	169	Knot	—	—	—	x	Knot.
8	170	Fire	(?)	(?)	—	x	
57	170	Frost crack	—	x	—	x	Frost.
67	170	Knot	—	—	—	x	Knot.
64a	175	Fire	x	—	—	x	Suppression xxx.
64b	175	Lightning	—	x	x	—	
52	178	.....do	—	x	x	—	Advance rot.
77	180	Fire	x	—	x	—	
71	183	Lightning	—	x	x	—	
95	185	Fire	x	—	—	x	Suppression xx.
39	191	.....do	x	—	—	x	Dominance xxx; fire 110 years ago; deep burn.
86	192	Frost crack	—	x	—	x	Frost.
14	200	.....do	—	x	x	—	
142	200	Fire	x	—	—	x	Condition very poor; suppression xxx.
73a	221	Frost crack	—	x	—	x	Frost.
73b	221	Lightning	x	—	x	—	
59	232	.....do	—	x	—	x	
141	258	Fire with frost crack	x	—	x	—	Advance rot.

Table IV is designed to show whether and in which cases typical rot extends much beyond the wounds forming the entrance for the fungus. Column 7 is the one to be followed ("Typical rot, extending much beyond wounds"). The affirmative is expressed by a cross, x, the negative by a dash, —. Cases which are on the line between the two are marked by a cross in parentheses; they are negligible for our purposes. The first tree to be considered, No. 58, is 123 years old and has a frost crack. From this age, or rather after 126 to 130 years, these cases become more and more frequent. In most cases, to judge from this table, frost cracks are a strong factor for extending typical decay much beyond the point of entrance of the fungus. By splitting the bole for a considerable length they allow air to enter the wood, which evidently stimulates the growth of the fungus.

In noting the cases of decay traced to the wounds or openings through which the fungus found its entrance, it is seen that two and even more cases of decay (cull cases) may be found on the same tree, but each case is counted separately. Where decay is traced to a combination of two factors, each factor is shown separately. The means of entrance of the fungus causing decay are thus shown to be as follows: Fire, 48; frost, 25; lightning, 23; other causes (including knots, girdling, etc.), 13; total, 109.

These 109 wounds (including knots, etc.) led to 97 cull cases. Out of 109, only 13 were other than wounds from fire, frost, and lightning, and 11 of the 109 cases of decay were the effect of a combination of two of the causes named. Fire has by far the greater share; frost and lightning are second, but the preponderance of fire and frost over lightning is greater than would appear, since they are far more serious with respect to causing decay. If ratings are given, more or less arbitrarily, but yet in keeping with our field observations, to the various causes of wounds in the order of their importance with relation to damaging decay in white fir, taking injury from lightning (the least consequential) as the unit, we have: Fire, 3; frost, 4; lightning, 1; other causes (including knots, girdling, etc.), 3. Then, multiplying the figures for means of entrance by these relative ratings we have: Fire, 144; frost, 100; lightning, 23; other causes, 39. These figures express the following facts: (1) Fire injury is not only numerically the strongest, but also commonly leads to considerable cull; (2) frost damage is less frequent (above all, less ubiquitous) than fire damage, because it appears only in typical frost belts or frost holes, but it carries decay over a much greater length of the bole; (3) lightning injury is fairly common, is also restricted to certain belts, and leads more often to superficial rot; (4) other factors are of importance as causes of damaging decay, but they are comparatively rare.

CONCLUSIONS AND OUTLOOK.

The interpretation of the results of this study of the white fir from a practical point of view can not leave out of consideration the fact that the basis for all computations and tables is a comparatively small one and that the actual figures and many of the principles derived therefrom have more the value of strong indications for local application than the force of general laws. Still quite a number of the considerations will be directly applicable, at least in all similar types, some throughout the range of white fir. The writer would emphasize again that the aim of the present study is not to lay down laws, but to show by means of one example the problems before us and the various steps leading up to a working method for the future establishment of laws which may—or may not—confirm the conclusions from this study, and to strongly advocate similar studies on a larger scale. With this point plainly in view, but assuming that our conclusions are a step in the right direction, we may discuss their bearing on the silvicultural problems that are before us.

DECAY IN RELATION TO WOUNDS.

In most cases, decay in white fir is caused by *Echinodontium tinctorium.* The mycelium never enters through the intact bark. Fire wounds offer the most common way of entrance; hence, in the majority of cases, decay starts in the butt; frost is less common than fire, but favors the vertical spreading of typical decay. Localized and superficial advance rot, frequently leaving enough merchantable timber in the log to make it worth while handling except when occurring in the upper part of the bole, is often connected with lightning. Other means of entrance, such as knots, wounds from falling trees, and girdling by rodents are comparatively rare.

These factors group themselves naturally into such as are uncontrollable and such as may be controlled directly or indirectly. The entrance of decay through knots, wounds from trees and limbs thrown in heavy storms, or from excessive snowfall lies beyond our control. Injury from mammals as a starting point of decay is very rare and will become even more so with the decrease of the forest fauna.

The other factors are more or less open to influence. Fire is distinctly a directly controllable factor. Lightning and frost are, of course, not directly controllable. It is a fact, however, that both do not occur to any damaging extent except in more or less well-defined belts, and generally more heavily in foci inside of these belts. The natural inference would be not to favor white fir in such belts when possible. As a first step in this direction the establishment and mapping of frost belts, frost holes, lightning zones, and lightning foci would be of particular value, which should not be confined to white fir alone. Other forest trees are also more or less subject to injury from both factors. The value of such maps should also make itself felt in forest-fire control, for the proper distribution of protective forces and improvements.

FOREST REGULATION.

CARE OF VIRGIN FORESTS.

It has been heretofore pointed out that practically the only means of silviculturally influencing the national forests on a larger scale at the disposal of the administration at the present time lies in the handling of timber-sales areas. On all the vast forests outside of these comparatively restricted areas the same beneficial and injurious conditions must continue to prevail, which on one hand govern the annual increment and on the other make for annual total loss. Only one single component of the total-loss factor, though a most important one, may be controlled to a certain degree directly. Forest fires are in ever-increasing ratio eliminated from the national forests and, therewith, also the danger of trees being fire scarred and opened to the attacks of heartwood-destroying fungi. But the best of fire protection can not restore to their original state of intactness the overwhelmingly large number of older trees which have been opened by previous fires. The open fire wounds continue to offer an easy entrance to fungi. It is true that fire protection prevents small wounds from becoming larger and keeps healing wounds from being opened again by repeated fires. The sooner such fire-wounded trees, as well as all other undesirable individuals, including all badly injured, diseased, and misshapen ones, can be eliminated from the forest, the better. There is little hope, however, for this to be done outside of timber sales. Adequate fire protection, both of watersheds and of commercial timber, must of necessity be paramount to silvicultural work of this kind.

Practically virgin forests may also be influenced by sowing and planting. This is done on so small a scale, compared to the total of existing forests, that we can hardly speak of any real silvicultural change. Knowing, however, that white fir can not be expected to yield full returns in belts subject to lightning and severe frosts, the forester should avoid favoring white fir in such localities.

FOREST REGULATION THROUGH TIMBER SALES.

Cutting timber does not in itself constitute sound silviculture. It may lead to regulation, or it may spell ruin to the forest.

The administration of the national forests is not able to have timber cut by selling it where cutting is most needed. Accessibility, local demand, and last, not least, the quality and condition of the timber are stronger factors in finally locating a timber-sales area than silvicultural needs. A strong admixture of inferior species in itself is often sufficient to let an otherwise attractive sale fall through. Here, the prejudice of the purchaser against such species as white fir and incense cedar is responsible for forcing the Forest Service to leave an area badly in need of improvement in its virgin state, with all the cumulative risk to which it is exposed. The prejudice against white fir is widely established and not always confined to the lumberman.

From a silvical point of view the prejudice is directed against its very aggressiveness, which tends to give the species an ascendency over the more valuable but less tolerant pines. But the disfavor in which it is held by the forester is really nothing but a reflection of the strong objection made by the purchasing lumberman to accepting white fir in Government timber sales, and this is based mainly upon the unsoundness of the timber. At the same time, there is a fair local demand for sound white fir for a number of uses. There is no valid objection to clear and sound white fir. In fact, many a purchaser would rather pay higher stumpage for white fir if he were allowed to take only sound young stuff, which is in demand for dimension stuff (2 by 4, 4 by 4, etc.), for frame stuff, timbers, and stickers, and for butter boxes, etc. Purchasers complain that much of the material, though seemingly sound, "has no life" after going through the mill; it becomes brittle and falls to pieces when dry. Sound white fir neither becomes brittle nor does it fall to pieces. It is the unsound material (advance rot) only which is objectionable. The remedy is easily seen; it consists in liberal and judicious scaling, which would rather give the purchaser the benefit of the doubt. The scaler will find valuable aid in the occurrence of decayed knots on the boles of trees affected with stringy brown-rot. To the casual observer they may appear normal; when they are knocked off with a hatchet or similar instrument the decayed rusty interior is exposed. These "rusty knots" afford, in the vast majority of cases, a valuable indication of more or less far-gone Echinodontium rot in the heartwood of white fir. Occasionally, the rusty color is missing, but the center of the knot is unmistakably decayed. The verdict as to the rottenness of the heartwood will be the same. The knots are often very small. When sound, they are very brittle and glassy in appearance. To give a practical example:

No. 82 on the Otter & Burns tract, a very fine tree with a long clear bole, 29.4 inches diameter breast high, and 154 feet high, had been given a full scale. The bole had been bucked into 16-foot logs. To the scaler there were no indications of decay. After examining the tree the writer threw out log 5. The only indication for spotting Echinodontium decay in this log was the presence of the rusty knot. The log was opened and found to be unmerchantable from 0.5 to 5.6 feet from the lower end, leaving as merchantable 0.5 foot on one end (diameter 19.5 inches) and about 10 feet on the other end (upper diameter 16.3 inches). Had the defect been known to the bucking crew a more advantageous dividing up of the bole in log lengths to the exclusion of the decay would have meant a saving to the operator.

Among others, Bryant[1] has pointed out the necessity of more judicious bucking and of closer utilization.

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[1] Bryant, R. C. Waste in cutting timber. *In* Amer. Forest., v. 19, no. 11, pp. 790–799, 7 figs., 1913.

MARKING.

The entire silvicultural results obtainable by way of timber sales are directly dependent upon proper marking, the importance of which can not be overemphasized. Marking is by far the most portentous of all silvicultural activities and requires a very specific training, of which a complete knowledge of all components of the total-loss factor must be a prominent part.

Marking in the selection forest has a threefold object—to select trees to be cut and utilized at once, to leave others as a basis for future cuttings, and to establish desirable reproduction. Here the interests of the Government as timber owner and timber producer frequently conflict with those of the purchaser. The purchaser can not be expected to take a strong interest in the future of the area he is to cut over. He quite naturally wants as much sound merchantable timber from a given stand as possible. The larger the amount of timber he can cut from an area the smaller the overhead charges will be per thousand feet, board measure. In offering white fir for sale it is, therefore, important to be able to estimate more or less correctly the amount of sound timber on a given tract. If our figures prove correct, the loss factor in white-fir trees will be comparatively small up to an age of about 130 years; after trees with a combination of wounding and suppression have reached the age of 130 years they are liable to contain decay; after they have reached the age of 150 years wounding alone, even in dominant trees, is liable to lead to damaging decay. That trees with sporophores are decayed, at least partly, is self-evident. The actual cull per cent from decay is at present only guessed at. It is the constant aim of forest pathology to reduce this guesswork to actual and concrete figures. It is intended to repeat similar studies throughout the range of white fir and later also on other species in the order of their importance and finally to establish broad zones of equal pathological conditions, in which the rot percentage may be given in definite figures.

Marking can only be done correctly if the outcome of the marking with regard to the trees left standing is constantly kept in mind. In our specific case, for instance, white fir on typical lightning and frost belts should be marked very heavily. We know that here the loss from decay, particularly following frost cracks, is heavy and will grow through cumulative risk. White firs with serious wounds, especially with partly open fire wounds, must be marked heavily to as low a diameter as practicable.

On the other hand, thrifty unwounded trees, where desirable, may be left without much risk up to the age of about 150 years, and probably much longer.

The effect of logging on the pathological condition of white firs that are left on the area may be twofold. The opening of the crown cover through cutting will prove beneficial to all suppressed and intermediate white firs. The ready response of the species to light is well known. It is probable that such trees, if already infected, will not allow the decay to proceed very much farther, i. e., the newly formed upper logs may be sound. These trees move up into the dominant class. The mycelium in the heartwood, however, if well established, will not die out, and after a while sporophores appear which carry the disease to hitherto sound trees. As there can not be any infection except through spores coming from sporophores on diseased trees, it is evident that it is poor silviculture to leave individuals infected with any parasite of economic importance on cut-over areas. Such trees on timber-sale areas should be marked and cut under all circumstances if we expect to save and utilize the sound timber they may contain and to protect other trees from decay. Sanitation of the forest must be the first and fundamental step in forest regulation. The introduction of the so-called sanitation clause in the timber-sale contracts of the Forest Service aims at this very point.

It is evident that blind enforcement of the sanitation clause, following the letter and not the spirit of the principle expressed, is just as pernicious as laxity in its application. Not all parasites are of equal importance; our efforts should first be concentrated on the most dangerous ones. The time will come when forest sanitation will include all controllable elements making for loss in timber volume and timber values.

On the other hand, if only thrifty trees are left standing after logging operations, they are, by the very opening of the "forest screen," more exposed to flying spores from surrounding untreated tracts, but unless wounded they are in no great danger of infection. The smaller the tract, the more will this influence make itself felt. The improved conditions under which they grow will help them to either overcome or limit the extent of decay in case they do become infected. As long as we do not possess any exact figures on the recovery of white fir on cut-over areas, however, it is advisable to consider wounded white-fir trees left standing as unaffected by the opening up of the stand, at least during the transition period, that is, in first fellings. All these trees have grown up under unfavorable conditions, and the chances that they are lastingly injured are considerable. By the time second logging operations cover the area, it is to be assumed that a more profound knowledge of the life history of white fir will be at hand.

The choice of white-fir trees to be left on the area, with the expectation that they will be sound and merchantable at the next felling, depends altogether on their condition and the length of time probably elapsing until that felling takes place. Assuming that our figures are correct and that the next cutting may occur, for example, in 30 years, we may with comparatively small risk leave thrifty unwounded trees of any age on the area; wounded but thrifty trees of more than 120 years are to be cut, wherever practicable, because in 30 years they will be over 150 years old, at which age trees of this class are more liable to deteriorate. Wounded trees which at the same time are suppressed should be eliminated. It is bad silviculture to leave individuals in the forest which not only do not produce the maximum of timber but which in all probability will prove a total loss and which occupy the place that should be fully stocked with trees promising a full and sound crop. In case of an emergency, such as occurs under very unfavorable market conditions or where the protection of young stuff is the most important feature, wounded and suppressed white firs left standing should not be older than 100 years, since in 30 years they will have reached their critical age—that is, 130 years. After they have reached this age it appears that damaging decay becomes prevalent in trees of this description. Very severely injured trees have, of course, no place in the managed forest. The same is true for unusually suppressed or unhealthy trees, unless it may be expected with reasonable certainty that the opening of the crown cover will benefit them materially. Trees with open fire scars and with open frost cracks should be cut in preference to those with lightning scars or those having wounds from falling neighbors. In short, all wounds reaching far into the wood are to be given a higher rating with respect to decay than superficial wounds unless the latter are unusually large.

PATHOLOGICAL ROTATION AND CUTTING CYCLES.

Since we may expect that cutting during the period of transition will practically eliminate all those trees which by their combination of suppression and wounding become subject to early decay (critical age), the age of decline forms the basis for what might be termed the "pathological rotation," for want of a better expression. It does not indicate that a given species should most advantageously be cut in regular intervals expressed by the pathological-rotation age, but that it should not be cut at a higher age. It is really a factor limiting the rotation and therefore also the cutting cycle.

Rotation based on maximum volume alone can not be more than a makeshift during the transition period; logically it should be narrowed down to maximum-volume production of sound timber. Such species as *Sequoia gigantea* and *Sequoia sempervirens* are so resistant to decay that their pathology will not influence their rotation at all. In some of our valuable pines the pathological rotation will probably be very high, either coinciding with or reaching beyond the age of maximum-volume production. In white fir, incense cedar, and a number of other so-called inferior species, the pathological-rotation age is presumably lower than the age of maximum-volume production. We must look to forest mensuration for final data to settle this point.

Barrington Moore [1] advocates a rotation based on the "period during which the rate of volume production is greatest or shortly after it, provided it is long enough to give the most valuable product."[2] Here, again, the pathological rotation will be the limiting factor, except for species in which the rate of greatest volume production possibly occurs at a lower age than the pathological rotation. That the value of lumber grades is bound to play a far more important rôle in the future than at present, with regard to rotation, is a foregone conclusion.

So far, we have considered only the rotation per species. In pure or almost pure stands the rotation of the unit is determined by the rotation of the species clearly dominating, not only numerically, but also in value.

As soon as two or more equally valuable commercial species appear together in about the same proportion, the rotation of the stand becomes "synthetic;" that is, the rotation for the unit is governed by the individual rotations per species. In the great majority of cases neither the representation of the species nor their individual values are the same. Nearly always there will be certain species more desirable than others, which latter then are classed as more or less inferior. A weak representation of inferior species with low pathological rotation will be without much effect upon the synthetic rotation of the unit. The stronger the representation of inferior species, the heavier will be their bearing on the synthetic rotation.

On many of the large private holdings of the West the inferior species are disregarded altogether; they are simply left standing in logging operations. Unless the logged-over area is burned, the representation of inferior species is then an unduly heavy one. They must necessarily dominate the stand in the future.

The national forests, on the other hand, will be the regulated forests of the future. In many of the national forests, particularly in the West, several species of unequal value are represented on the same unit in such a manner as to make each one a strong factor to be considered. Here, regulation of yield must be based upon synthetic rotation and synthetic cutting cycles. Rotation and cutting cycles for each species must be determined separately, each on the chosen basis of either maximum-volume production, or rate of maximum-volume production, or production of maximum value, limited in

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[1] Moore, Barrington. Chapman's method of studying yield, p. 94, 1913. To accompany forest plan, Plumas National Forest, district 5. Appendix (continued), Silviculture. (Unpublished. Furnished by courtesy of the U. S. Forest Service.)

[2] See also Zon, Raphael, Balsam fir, U. S. Dept. Agr., Bul. 55, 68 pp., 2 pls., 8 figs., 1914. (See p. 67.)

every case by the age of decline. The synthetic rotation is figured on the basis of the specific rotations, under due consideration of representation and relative value of each species from a commercial and silvical point of view. The same is true for cutting cycles. It should not prove impossible to express both representation and relative value for each species in symbols, which, together with the specific rotation, would permit the balancing of each species against the others, and thus to arrive at the synthetic rotation of the entire unit. In this way the inferior species will be given their proper place in forest regulation. This procedure is undoubtedly followed more or less consciously wherever regulation is planned by way of timber sales. It can not be reduced to a practical working system, however, until all factors upon which it is based are thoroughly known.

The pathological rotation limits the rotation of white fir, on the basis of our present knowledge, to 150 years—at least during the transition period. Perhaps the actual felling age for the species will be shortened long before that time arrives. The chances of providing for the next decades are distinctly better. On areas cut over to-day we may expect second operations in not too remote a future, taking the place of a second improvement felling. Provided our figures prove correct, the critical age and the age of decline will be a safe guide in tentatively fixing cutting cycles for white fir, which, together with the cutting cycles for the other species present, will permit the establishment of the synthetic cutting cycle for the unit.

Our present knowledge of the pathology of white fir leads us to the following practical conclusions for the period of transition:

- Prejudice against white fir as an inferior species.
  - Conservative scaling (excluding advance rot) in favor of the purchaser on the one hand and of better utilization of sound white fir (where market conditions permit) on the other will in time overcome the prejudice.
- Silvicultural treatment of white fir.
  - Reproduction: Frost and lightning zones are to be avoided.
  - Marking on timber sales:
    - On frost and lightning zones marking should be heavy.
    - Badly wounded trees, particularly those with open fire scars or frost cracks, should be marked heavily.
    - Badly suppressed trees should be marked heavily.
    - Trees with a combination of wounds and suppression can not be figured on to remain fairly sound beyond the critical age of about 130 years. The age of such trees, if left standing, added to the number of years to elapse before the presumable next cutting takes place, must not exceed 130 years.
    - Trees wounded, though thrifty, can not be counted on to remain sound beyond the age of decline of about 150 years. The age of such trees, if left standing, added to the number of years to elapse before the presumable next cutting takes place, must not exceed 150 years.
  - Rotation and cutting cycles.
    - The rotation for white fir, as far as we can judge now, can not exceed 150 years.
    - Cutting cycles for white fir must be limited by the age of decline.

OUTLOOK.

The weak point in the example (white fir) discussed in this paper lies in the fact that the numerical basis of trees examined is insufficient. Besides, what may be true for one set of conditions may prove wrong in another. Extensive additional studies on white fir in different regions of its range have been carried out during 1913.

What has been done for white fir must be done for the other species as well. Investigations on incense cedar have yielded suggestive results; others are to follow. But not before all important species, from the lowest to the most valuable, have been studied carefully with regard to their pathology can we expect to definitely figure the total-loss factor for any unit. To-day we are standing at the very beginning. Each species has its specific fungi, either one (as in the case of incense cedar), or practically one (as in the case of white fir), or several (as in the case of Douglas fir, sugar pine, and yellow pine). The relative importance of each of these fungi, their relation to influencing factors, their prevalence throughout the range of their hosts, and, finally, the establishment of the critical age and age of decline from a pathological point of view, are still to be worked out. To this we must add the study of all the other components of the total-loss factor.

The amount of work left to be done is enormous and will require many years. Concentration on the inferior species will yield results in a shorter time, enabling us to establish general rules to guide us in the transition period without causing too much damage to the interests of future generations.

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