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QUAKING ASPEN. A STUDY IN APPLIED FOREST PATHOLOGY
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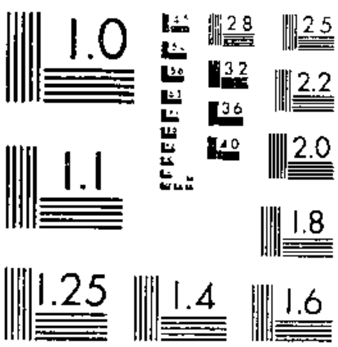

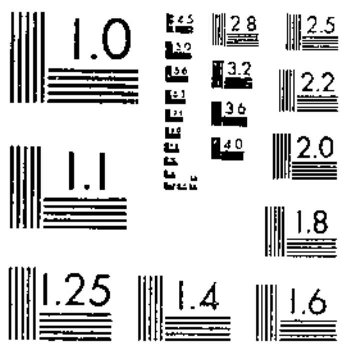

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QUAKING ASPEN: A STUDY IN APPLIED FOREST PATHOLOGY

By E. P. MEINECKE

Principal Pathologist, Office of Forest Pathology, Bureau of Plant Industry

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INTRODUCTION

In the management of quaking aspen (*Populus tremuloides* Michaux), as well as of any other species of forest tree, two factors are of decisive influence, namely, the possibility of securing the maximum volume production in sustained yield on a given area and on the other hand that of reducing to a minimum the loss from decay and other injurious factors. Maximum volume production must mean the maximum yield of sound high-grade lumber obtainable from a given species grown under given conditions. The definition of high-grade lumber will depend in each case on the use to which the lumber is to be put.

Aspen in Utah, largely owned by the Government (*1*),[1] has in the past found a limited market as mine props and a local use as posts, poles, and fuel. To-day coniferous props have more and more taken its place in the coal mines of Utah. Unless new uses can be found, aspen will have to be considered as a weed tree, and as such will rank with the lowest of the inferior species. Its value as browse does not lie within the scope of this study.

[1] Reference is made by italic numbers in parentheses to "Literature cited," p. 33. The data offered in the present study are based on investigations conducted for the intermountain national forest district and have been used in F. S. Baker's bulletin (*1*).

The utilization of aspen for pulp in other parts of North America has suggested a similar use of the species in the intermountain national forest district. The present investigation is, therefore, based entirely on the assumption that aspen in Utah may in the future find a ready market for use as pulp and perhaps also as excelsior and matchwood. Obviously, the growing of aspen can be profitable only if the loss from decay and other factors does not cut too heavily into the expected yield.

That aspen in the storage pile is highly susceptible to the attacks of saprophytic fungi is well known. The losses from this source are extremely heavy. In this study, however, the cull factor will be considered only as it affects standing timber.

In wood used for pulp where the raw material is mechanically broken up into minute particles, the cull factor must play a rôle entirely different from that in saw timber. Nothing definite is known as to the proper procedure for estimating the amount of cull from decay in quaking aspen. Under present commercial practices, culling for rot is rather lax on account of the heavy demand and the growing scarcity of pulpwood. The manufacturer can not afford to pay top prices. He must use inferior grades and naturally expects a certain amount of rot.[2]

That decay very materially affects the weight is shown by Kress and Bearce (*9*). Studies by the Forest Products Laboratory, Madison, Wis., show that there is an appalling loss to the paper industry from decay. Correct determination of these losses can not be arrived at by the cord or volume measurement of pulpwood, which latter, while undergoing decay, suffers no change in volume, but does decrease decidedly in weight. Scalers attempt to estimate rot in wood, but this estimate is arbitrary and often incorrect. Examination of a number of shipments of infected spruce shipped to the Forest Products Laboratory for pulping trials showed a maximum variation in comparison with sound wood of 5 pounds per cubic foot of bone-dry wood. This represents a loss of 19 per cent on actual wood substance.

No information whatever is available to serve as a basis for the use of loss in weight as a criterion for the pulping value of decayed aspen wood. It is known that *Fomes igniarius*, by far the most common and most destructive of the fungi attacking quaking aspen, first breaks down the lignins in the cell walls, leaving fragments of cellulose which in their turn are consumed as the decay progresses. Schmitz (*13*) has demonstrated the presence of cellulase and hemicellulase in the mycelium of *F. igniarius*. Nothing definite is known as to the rate at which the reduction of the cellulose content proceeds. But it seems fair to assume that in the latest stages of decay, which are characterized by pronounced softness and loss in weight, such changes have taken place that the wood is no longer useful for pulp. In the lighter stages of decay, not accompanied by pronounced softness and loss in weight, the cellulose content may be considered as not seriously impaired, though the lignins may already be partly consumed. In the course of the study in the field the decays were

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[2] Thanks are due Otto Kress, formerly in charge of the section of pulp and paper, Forest Products Laboratory, Madison, Wis., and to J. D. Rue, in charge of the section of pulp and paper, Forest Products Laboratory, for the facts and considerations given in this section of the bulletin.

arbitrarily classified according to hardness and consistency, due consideration being given to apparent loss in weight.

OBJECTS OF THE STUDY

The objects of the present study can be summarized as follows:

1. Determination of present cull per cent per age class in standing aspen intended to be utilized for pulp, the cull being expressed in volume and in degree of hardness. Since even decayed aspen wood may be expected to make pulp as long as the decay has not progressed too far, only those cases of decay are included in the cull in which the wood has become soft and cheesy and has lost materially in weight. Earlier stages of decay, not accompanied by decided softening and loss in weight, are considered as negligible and are therefore not culled. Causes for cull other than decay are rated according to whether they are likely to interfere with the pulping process. Lightning scars are negligible. Frost cracks and shakes, which are so prolific a cause for cull in saw timber, have no direct bearing on the quality of the pulp, nor do they interfere with the pulping process. In fire scars the immediate loss is one of actual destruction of wood mass. Insect borings cause a direct loss in weight, though this is rarely of much importance. The wood separating the individual galleries is not depreciated for pulp purposes as long as it is not decayed. More difficulty was encountered in determining what should constitute cull for canker. Barking is an important item in the pulping process and requires for perfect functioning more or less even round sticks. Cankers interfere more or less with this requirement. No hard and fast rule can be set for culling on account of canker. Each case has to be considered individually on its own merits, on the basis of a probable interference with the mechanical handling of the stick.

2. Determination of the age beyond which decay in aspen becomes economically important. Very young trees are little subject to culling factors or are killed before they become established as permanent members of the forest community. With increasing age they are subject to cumulative risk (*11, p. 9*) from a number of injurious factors, among which decay is one of the most important. Fungi, like all other plants, demand for their proper development a minimum mass of substratum from which to draw their subsistence, some, such as molds, being content with very small quantities; others, like the common heartwood-destroying fungi, being able to live and fully develop only in larger masses of wood in which they find proper living conditions and room for expansion. The older trees, then, present conditions more and more favorable for the growth of the group of fungi causing cull in living aspen. Studies in white fir (*Abies concolor*) and incense cedar (*Libocedrus decurrens*) have shown that, although both species are susceptible to infections by heartwood-destroying fungi soon after heartwood begins to be formed, decay does not become economically serious until the trees reach a greater age. The determination of the age class from which onward the loss from decay tends to reduce materially the gain from increment in the virgin forest furnishes a basis for the pathological felling age. The determination of the age class from which onward the loss from decay tends to reduce materially the gain from incre-

ment in the managed forest from which all undesirable individuals have been eliminated permits the establishment of a pathological rotation, indicating the period beyond which it will be unsafe to leave aspen uncut on account of the loss to be expected from decay.

PATHOLOGY OF ASPEN

Quaking aspen is highly susceptible to disease (*5*). The increment of wood added is more or less severely affected by a number of leaf diseases. *Sclerotium bifrons*, according to Hartley and Hahn (*5*), is common and of some importance in Colorado and sometimes is responsible for the killing of half of the foliage of considerable forest areas. In Utah the fungus seems to be negligible so far, but will bear watching. A leaf rust, *Melampsora albertensis* Arth., is common but does little damage. *Uncinula salicis* also is common but of minor importance. A leaf spot, closely related to *Marssonia populi*, but differing from it somewhat in spore characters, is exceedingly common in the region studied and can not be without influence on increment.

The bark of quaking aspen in Utah is subject to a number of troubles, of which canker is by far the most frequent and serious. (Pl. 1.) The cause of this disease is still unknown. Several fungi have been observed (*5, p. 145; 8, 10, 12*) in connection with cankers in other parts of the country. None of these appears to be involved in the Utah aspen canker. It seems, however, to be closely related to, and perhaps identical with, a canker type of unknown origin described by Long (*10, p. 332*) as occurring on older trees in Arizona and New Mexico. Little of a definite nature can be said even of the development of the canker. Not all infections, if infection there is, are able to survive. Often the canker growth stops, and the affected area heals over. Whatever the primary cause, the canker is characterized by a local killing of the bark which, especially in thinner stems, may lead to complete girdling and killing. In other cases a callus around the killed area is formed which may in its turn be attacked and killed back. Typical older cankers present a central dead area surrounded by a series of calluses from which the old rigid bark stands out in ragged fragments. (Pl. 2.) Often the cankers grow to very large size and disturb the symmetry of the bole locally to such an extent as to render it unfit for any use for which round timbers are required. Canker is beyond doubt a serious menace to aspen growth. It is firmly established in Utah and very common. The fact that it occurs principally in isolated foci within which almost every tree is affected, while adjoining areas are free from the disease, suggests an infectious origin and therewith the possibility of local control by systematic elimination of cankered trees or cankered branches and limbs.

The wood of standing quaking aspen is attacked by several fungi, foremost of which is *Fomes igniarius* or false-tinder fungus. The fungus causes a typical white rot of the heartwood, but later the mycelium attacks the sapwood also and may reach the cambium. At first brownish streaks appear in the still firm wood. Later the wood becomes white, dry, and very soft, so that it cuts more smoothly than soft pencil wood—much like dry cheese, but for the stickiness of the latter. In this stage it resembles closely balsa wood (*Ochroma lago-*

Aspen stand in central Rocky Mountains heavily affected by canker

Individual old canker with flaring bark fragments *pus*). The transition from the first stages of decay to the cheesy stage seems to take place rather quickly, at least under conditions favorable to the growth of the fungus.

Fomes igniarius follows aspen throughout its range, and everywhere heavy loss goes with it. Hartig (*4, p. 114*) was the first to call attention to its extraordinarily destructive properties and to give a detailed description of its morphology and the peculiar mode in which it attacks the wood of its hosts. Weigle and Frothingham (*15*) state that in Maine and New Brunswick the immense stands of aspen which followed the fires of 1825 are so rapidly deteriorating from white rot (*F. igniarius*) that many of these 80 to 90 year old stands must now be culled by from 5 to 20 per cent. These writers give detailed examples of the heavy losses from decay encountered in individual logging operations. According to Cameron (*3*), at least one-half of the aspen around Lesser Slave Lake in Canada is useless, owing to the attacks of *F. igniarius.* Von Schrenk and Spaulding (*14*) state that in the New England States, in Colorado, and in New Mexico it is almost impossible to find healthy stands of aspen that have attained any age, because of the extreme destruction brought about by *F. igniarius.*

Second in importance is *Fomes applanatus*, though not nearly so common as the former. It causes in aspen a light-colored rot of the heartwood, sometimes extending into the sapwood. *F. applanatus* is generally confined to the butt of the tree and therefore rarely becomes economically important, though it may be locally destructive. White (*16*), in a detailed study, considers the fungus as a parasite which generally enters the host through a wound on a root near the collar or on the trunk. It works inward to the heartwood and thence upward, involving the lower sapwood. Though the decay is largely confined to the lowermost few feet of the trunk, it may occasionally extend upward some 12 or 15 feet. In early stages the wood shows a characteristic mottled appearance. At this stage the wood is still hard and heavy. The final stage of decay is indicated by uniform white color of the wood. By this time the wood has become very soft and light in weight and rather spongy. Heald (*6*) states that the fungus enters the base of the trunk near the ground line and that, in specimens observed, the decay reaches a height of 10 feet. The wood becomes very brittle. He found no infected trees below the age of 30 years. Hedgcock (7) reports this fungus from the Manti National Forest near Ephraim, Utah—that is, from the locality where the present study has been conducted—as causing a serious root rot reaching into the butt of the tree; he attributes to it considerable loss on moist slopes. The writer also has observed the fungus in the same and other localities in Utah. The fungus does not seem to fruit freely on the area under investigation. In the course of the study only two cases of decay from *F. applanatus* were found that were connected with sporophores, both of these being in the stump and causing only negligible loss. The close analogy with the action of *F. igniarius* justifies the assumption that here also pronounced loss in firmness and weight in the uniformly white stage is accompanied by chemical changes which render much decayed wood unfit for pulping.

A very similar decay occurring on the area studied tallies with the familiar decay of *Fomes applanatus* except in two points. It seems to be confined to the heartwood, and in severer cases the affected wood degenerates into a very stringy, wet, and soggy mass, of a character so far not described for *F. applanatus*. White (*16, p. 158*) has found that purely secondary saprophytic bacteria and fungi practically always appear in the advanced stages of decay caused by *F. applanatus*. It is not impossible that the stringy and soggy consistency of what is here called "stringy butt rot" is due to a further disintegration by secondary fungi and bacteria. Like the decay of *F. applanatus*, it is typically a butt rot which, in all respects except the two mentioned, resembles *F. applanatus* decay so closely that one is inclined to attribute it to this fungus. Although the total absence of sporophores connected with this stringy butt rot made definite identification in the field impossible, the close similarity, coupled with the fact that *F. applanatus* is known to be not uncommon in the region under investigation, may justify a tentative listing of this stringy butt rot under *F. applanatus*. In general, the type of decay is akin to that of *F. igniarius*, so that for the practical purposes of this study pronounced loss in firmness and weight was made the criterion of cull for the stringy butt rot as well as for genuine *F. applanatus*. The stringy butt rot contributes only slightly to the total loss from decay, and the possible error hardly influences the final results.

A number of minor secondary decays are very common, never reaching an extent or degree of rot, however, which could have any bearing on the use of the affected wood for pulp. In the absence of sporophores, the determination of the causative fungi is impossible except through laboratory cultures, which at the time of the study was not feasible. These decays, while noted and measured, are considered unimportant and negligible for the purposes of this study. None of them is liable to influence the loss factor.

All in all, sporophores of wood-destroying fungi are relatively infrequent in this region.

PRINCIPLES AND METHODS OF INVESTIGATION

The immediate vicinity of the Great Basin Range Experiment Station, Utah, located at an elevation of 8,750 feet, in the Wasatch Range of the Rocky Mountains, was chosen by local members of the Forest Service as representing good average aspen for Site I. A comparison with Baker's data indicates that the area covered stands rather between Sites I and II. It goes without saying that the results presented in the following pages hold good only for the area surrounding the Great Basin Range Experiment Station and other areas comparable to it. But since it is not to be assumed that aspen on the poorest sites will be utilized or put under management for pulp wood, the general conclusions will be valid for all sites likely to be considered.

FIELD METHODS

The methods used in the field were much the same as those first used by the writer in the study of the pathology of white fir (*11*) and later by Boyce (*2*) for incense cedar. They were, however, adapted in the field to the altered conditions arising from difference in the species concerned, size of trees, and the special object of the study. Suitable smaller areas were selected on which every tree was cut. On other areas a certain selection of trees was made so as to secure as closely as possible a cross section through the stand, within certain age and diameter limits, the aim being to obtain data on all trees which could be regarded as truly representative of the merchantable stand as it actually exists, with regard to its utilization in the near future. For this reason the analysis of seedlings and saplings below 30 years of age and of all trees plainly outside of the limits of possible utilization—such as trees unusually misshapen and distorted or trees which obviously were dropping out of the permanent stand—was excluded.

In conformity with the object of the study, an effort was made to balance the different age classes as nearly as possible. Exact data were taken for each tree on diameter breast height, height, crown class, age at stump (1.0 foot), diameter inside bark at stump (1.0 foot), diameter inside bark at the upper end of the 8-foot logs to 2 inches diameter in the top, and, where this last was impossible, the diameter inside bark at 2 inches diameter was computed. Particular attention was paid to description and location of wounds of different types on the bole, sporophores, etc. The trees were bucked in 8-foot lengths, and careful diagrams were drawn of each cross section, giving in detail and with exact measurements the extent of decay and of internal wounds. The individual logs were split and the decay as well as wounds measured, described, and sketched in a longitudinal diagram. Wherever feasible, the point of entrance was determined through which decay had established itself in the tree.

Decay was accurately described and graded. Specimens of different grades of decay were collected, in order to permit checking of the field notes in the laboratory.

In the course of the study it was soon found that *Fomes igniarius* decay and a "stringy butt rot" (*F. applanatus?*) were the only factors causing, in the later stages, such loss in firmness and weight that cull, in the sense discussed above, ensued. Of these, *F. igniarius* is by far the more common and important. For the sake of completeness equally accurate data were taken with regard to incidental minor decays caused by a host of undetermined mycelia, all of which are classed as secondary. These secondary rots also enter through wounds but never penetrate deeply into the wood, generally being confined to the immediate vicinity of the wound or opening itself. They are without importance from the point of view of utilization for pulp.

COMPUTATIONS [3]

All volumes were figured in cubic feet inside bark. The bole was considered as a paraboloid, but the stump was figured as a cylinder with the diameter of the stump-cut at 1 foot, and the top as a cone above the highest diameter measurement. Limb and branch wood was not included. In accordance with data furnished by Doctor Kress, Forest Products Laboratory, the merchantable volume was figured from the stump to 2 inches (diameter inside bark) in the

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[3] All questions of mensuration were first submitted to Donald Bruce, division of forestry, University of California, to whom thanks are due for the great interest he has taken in this phase of the study and for the valuable advice given.

top. Where it was not feasible to obtain the height to 2 inches (diameter inside bark) in the top by direct measurements, the volume to this point was computed by the following formula: $V=\frac{H}{3}\left(B-\frac{0.044}{D}\right)$ in which D = last (highest) diameter taken, N = volume of the frustum of a cone between the point where D is taken and the 2 inch (diameter inside bark) point, H = height between point where D is taken and the tip of the tree, and B = basal area of D. Volumes of logs were computed by the Smalian formula, average diameters at the ends of logs being used.

In general, forks and broken tops were disregarded, and the longest fork or the longest volunteer was taken as the leader.

PRINCIPLES OF CULLING

The actual volume of wood immediately affected by decay, canker, fire scars, etc., was first figured as "net loss." The "net cull" is the volume of the log or part of the log rendered unmerchantable by the net loss factors, including, for example, thin layers of sound sapwood which could not be utilized independently.

In those simple cases in which heavy decay runs throughout the entire wood of a log, as for instance in severe attacks by *Fomes igniarius*, the net cull represents the loss from a commercial point of view. But frequently there are complications, where, for instance, two streaks of decay or decay and a fire scar run so close together that it will not be possible to utilize the sound wood separating them. In such cases the net cull volumes from both causes plus the volume of sound wood rendered unusable is totaled as "gross cull." Gross cull, in the final analysis, is the total commercial loss, so that in the case of a log completely destroyed by *F. igniarius* the net cull volume equals the gross cull volume. In other words, the gross cull corresponds to cull deduction to be made from the total gross scale.

For the purpose of figuring the cull per cent of the stand, only gross cull volume, the grand total loss from all causes, is of interest. For the proper understanding of the rôle played by the various injurious factors themselves, fungi, fire, canker, etc., however, the net cull volumes must be used. The mere fact that two cull volumes happen to be placed so close to each other in the bole as to render the sound wood separating them commercially valueless can not justify a procedure in which this volume of wood is charged against either one of the culling agencies.

In order to express intelligibly the degree of decay as observed in the field, it was found advisable to adopt three grades. The first grade represents genuine rot in a solid mass, causing so pronounced a loss in firmness and weight that the wood has to be considered a total loss for pulping purposes. The second grade covers the same kind of rot, but it extends through the wood in isolated streaks instead of forming a solid mass. The third grade indicates advance rot (*11, p. 33*), referred to by more recent writers sometimes as "incipient decay," and includes lighter decays of various origin involving no appreciable loss in hardness and weight. Grade 1 causes net loss of the entire volume it occupies. In grade 2 the streaks of decay cause net loss of the streaks themselves but not of the rest of the wood, and allowance is made on that basis. Grade 3 is considered negligible for the purposes of this study. It must not be overlooked, however, that both streaks and advance rot represent but earlier stages in the development of the fungi concerned and that both will in due time develop into grades 1 and 2, respectively.

Where heavy rot extends throughout or through most of the heartwood of a log or bolt, that log or bolt is culled completely as net cull (in this case equaling gross cull). Since logs of small diameter are not much less expensive to handle than larger ones, while proportionately the loss from decay, etc., is greater, culling should logically be heavier on a sliding scale the smaller the diameter of the log. Lacking such a sliding scale it was found advisable to cull logs or bolts below 6 inches in diameter more heavily than the large sizes.

When the rot volume extending through a log did not occupy the entire heartwood, the volume of the rot column was generally figured by the Smalian formula, because the form of the rot column through a log usually is that of a frustum of a paraboloid. What little variation from the paraboloid form there may be in such cases can lead only to negligible error.

The great diversity in form of the cankers led to some difficulty in culling. All degrees and transition forms are encountered, from the initial small stages to large flaring, highly irregular deformations, which latter, at least, can not be without influence on the barking process. Scaling for canker was therefore largely governed by considerations of presumable difficulties which smaller and larger, relatively smooth, and very ragged cankers might cause in the barking machine. In addition old cankers, in which a succession of irregular calluses had brought about pronounced deformations of the bole or distortions of the wood fiber, were culled heavily, while lesser injuries were ignored, in accordance with the fact that injuries other than rot are largely overlooked by the pulp industry. So far as known, canker, where present at all in the aspen regions now under exploitation for pulp, causes so little damage that no attention seems to be paid to it. In Utah, however, canker is so common and destructive a factor that it could not be left out of the equation in figuring the chances of a prospective pulp-wood enterprise. Whether the quality of the wood with regard to utilization for pulp is actually impaired remains unknown. Canker does not destroy wood already formed, but the wood lying underneath the canker is often stained orange red or dull orange and seems to be more brittle than normal wood.

The loss in local increment caused by the killing of the cambium is largely compensated by the excess growth in the calluses. Actual wood volume in a cankered area is apparently not much smaller than in the normal stem. The wood mass is simply differently arranged in space, and the area of the roughly triangular cross section through a canker may be the same as the area of a corresponding sound cross section. The more pronounced the deviation from the circle the greater will be the difficulties in working up the wood and the heavier should be the culling.

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COMPILATION AND TABULATION

The compilation of the data followed in the main the principles laid down in former studies (*11, pp. 36–46*). The basic material consisted of 240 trees, ranging from 30 to 168 years in age and from 2.3 to 18.1 inches, d. b. h. The representation from 41 to 120 years is fairly even. The 30–40 and the 121–130-year age classes have 15 and 14 trees respectively. Above 130 years the numerical bases become weaker, and the data can only be used with proper caution. The total merchantable volume amounts to 1,237.3 cubic feet.

The individual trees, arranged by their ages, are first listed on the "basic sheet," on which all fundamental measurements and data are entered from the field notes. The bare facts of the basic sheet are then analyzed and condensed. Obviously immaterial notes and figures are eliminated, and all pertinent facts are given in the simplest mode of expression consistent with accuracy and clearness. Those data which do not speak for themselves when expressed in figures are reduced to easily comparable symbols. One, two, or three crosses (x, xx, xxx) denote the relative degree of each factor. Three crosses are equivalent to the highest degree and one to the lowest, with two crosses as medium. The system has the advantage of simplicity, and readily adapts itself to different purposes where an understanding of general relationships rather than the presentation of definite facts is sought.

The relative importance of decay itself, when expressed in cubic feet, becomes apparent only through constant and cumbersome reference to the volume of the tree affected. The application of the cross system reduces the mass of figures to directly comparable values. The decay is rated in crosses on the following arbitrary scale:

X=0–10 per cent of the merchantable volume of the tree.
XX=11–30 per cent of the merchantable volume of the tree.
XXX=31–100 per cent of the merchantable volume of the tree.

On this basis x is a light grade, xx is more serious, xxx is very heavy. A cross in parentheses (x) represents a case with hardly even the value of x, so that (x) and x may be entirely disregarded from a commercial point of view, but not from the standpoint of the forester, since light decay may in time develop into serious damage.

In former similar studies it appeared that a relation exists between decay and rate of tree growth, that the slower the growth of the tree in the aggregate the greater the loss from decay. Rate of growth was expressed by the relation of the actual to the average volume of trees of the same age. In the present study the volumes, including stumps and tops, were averaged for each 10-year age class, after the age for the number of trees in each age class had been averaged, and a curve was constructed from the data obtained. In comparing the volume of the individual trees with the volume as given by the curve, seven groups were established, of which the middle one, coinciding with the values of the curve, is called standard. One, two, or three crosses indicate the degree to which the volumes of the individual trees fall below or rise above the standard, and on this basis the following arbitrary rating is adopted:

0–10 per cent deviation above and below=standard.
11–25 per cent deviation above and below=x.
26–50 per cent deviation above and below=xx.
51–100 per cent deviation above and below=xxx.

The percentages of deviation refer to the standard taken as 100. The terms suppression and dominance as used in former work are at best vague and could serve only in the absence of a better terminology. They are supplanted here by "above standard," "standard," "below standard." "Dominance" and "suppression" are terms denoting a relation of the tree to site, and for this the height index is considered to be a better indicator than volume over age. In the present case the emphasis is not on site but on the relation of wood-destroying fungi to individual trees of different physiological value. The tree itself represents the site for the fungus living in it.

That decay in forest trees stands in close relation to wounds is a well-established fact. Though certain fungi attack the tree through the roots, the great majority effect their entrance through open wounds which expose the wood. The chances for infection increase with the number and size of the wounds and with the length of time the latter remain open. These factors which play so important a rôle in the pathology of the trees can not be illustrated by simple figures. In the analysis of the basic sheet each wound is given a rating which expresses with the help of the cross system as clearly as possible its bearing on infection and on the functional life of the tree. A large fire scar, which may take 100 years or more to heal over, is rated very high, while the very thin cleft of a frost crack offering only a small opening into the interior of the bole receives a low rating. Canker ranks partly as a cause of wounds, partly as a physiologically weakening factor. Cankers form more or less large openings which give fungi free access to the wood. The killing of large patches of bark interrupts locally the free flow of assimilates and often approaches the conditions of a partial girdling. The rating of canker is based on the number of cankers on the individual tree and the relation of the killed bark surface to the total bark surface of the tree.

From the basic sheet the analyzed data are now transferred to the main sheet, on which the individual trees are entered by their ages. The main sheet with its condensed data becomes the principal working basis for final analysis.

ANALYSIS OF DATA

An analysis of the main sheet with its symbolized values brings out strongly the fact that age is an important factor in the occurrence of decay.

The first case of decay, though negligible, occurs in a tree 35 years old. Weigle and Frothingham (*15, p. 19*) state that in Maine and New Hampshire the aspens are attacked only after about the twentieth year, while Von Schrenk and Spaulding (*14, p. 32*) report that aspen becomes infected after the trees are 20 to 25 years of age. The age of infection simply indicates that trees beyond that age are subject to infection but not necessarily to serious decay.

That trees may in rare cases be badly decayed, even at an early age, is shown by a 39-year-old individual. The tree was heavily wounded and much below standard in volume and is the only seriously affected one among the first 67 trees of the main sheet. To put it in other words, the trees of younger ages, comprising 28 per cent of all trees tabulated, are practically free from economically important decay. The next trees where rot appears are respectively 57 and 62 years of age, and both trees are apparently without open wounds and above standard. The first has been badly cankered for 38 years, or since it was 19 years old. But again these are exceptions. In the following 28 trees only one case of medium importance occurs. From the age of 78 years upward, cases of heavy decay become more frequent, mostly in trees very much below standard and heavily wounded. A marked increase seems to come in the second half of the nineties and is more pronounced from 101 years on. Though heavy decay is still found in trees both much below standard and heavily wounded, the cases of serious decay in which one of these factors may not be present become more and more frequent. The turn seems to take place from about 111 years on.

The analysis of individual trees arranged by their ages makes it appear that in the wild stand, as it exists to-day, with its many wounded and slow-growing trees, decay becomes a factor of loss from the eighties on and causes serious loss from 100 years on. From about 110 years upward the loss is heavy in trees that are much below standard, although only slightly wounded, or in badly wounded trees although much above standard. Above that age even thrifty trees are likely to be seriously decayed.

Another point that is strikingly brought out is the steady increase in new infections with age. From 57 years onward, the increase is very noticeable. The older and larger the tree, the greater is the cumulative risk (*11, p. 9*) of wounding and, consequently, the chance for infection.

CUMULATIVE RISK

The cumulative risk is illustrated in Figure 1, based on percentages of trees infected. A few of the latter have two or even three infections. For practical purposes they are considered as one. It is of little more than academic interest to know whether a certain volume of decay is due to a single or to several infections. The lines show the general trend of infections with age, expressed in percentages of infected trees for 10-year age classes. The solid line combines all infections. From low levels it rises abruptly and steeply until in the 121–130-year class 93 per cent of the trees show infection. For the characterization of the two broken lines decay ratings are used, decay being nothing but the result of infection. The lighter, negligible ratings, (x) and x, have been united in the dotted line, while the third line comprises the heavier ratings, xx and xxx. The percentages of light decay ascend rapidly to the 60-year age class and then show a steady downward trend, contrasting with the sustained ascending tendency of the line for heavy decay, which swings up rapidly and markedly in the 91–100-year age class, running almost parallel with the line for the combined infections.

The following deductions may be drawn with safety. The risk of infection as well as the probability that an infection will develop into heavy decay are functions of time. Infections with heavy decay are rare up to the last decade of the first century of the trees' life and then gain rapidly in frequency of occurrence. Light decays are preponderant up to 60–70 years, after which age class they decline in number. Evidently many of the lighter infections turn into heavy decay after that age. A certain number taking place later in life never reach the stage of heavy decay.

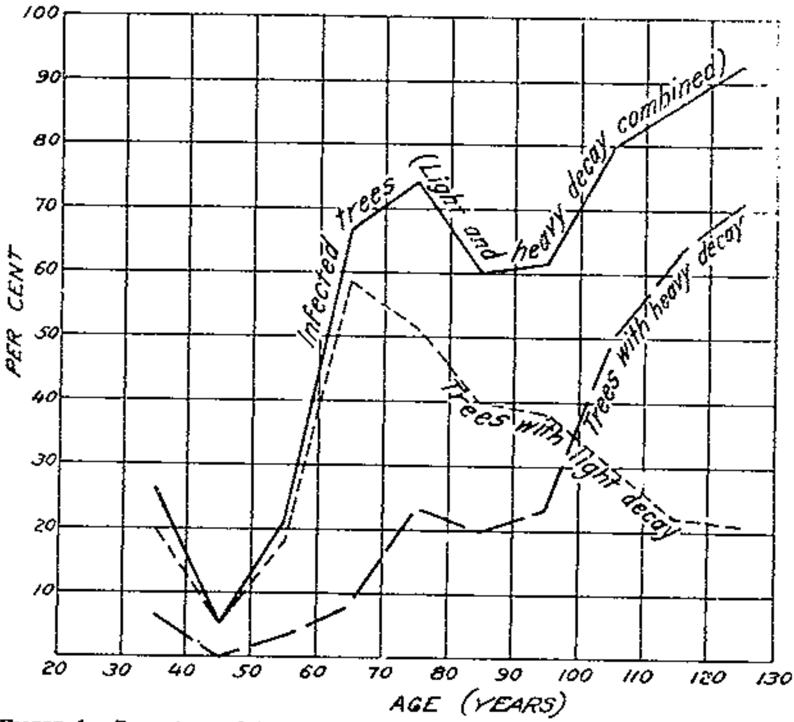

FIGURE 1.—Percentage of trees with infections, by age classes. The ratio of infected trees increases steadily with age. With time the infections develop into more and more serious decay

WOUNDS AND INFECTIONS

That most heartwood-destroying fungi are incapable of infecting a tree unless a wound offers an opening to the wood has been amply demonstrated. The term wound, therefore, applies here only to such lesions as expose the wood to infection. By far the greatest number of wounds in forest trees in general are scars caused by forest fires, by lightning, by insects, by logging, by wind breakage and bruising from falling trees and heavy limbs, and by frost cracks. In quaking aspen a specific factor, canker, is added to the list. Its peculiar rôle justifies a separate treatment of the subject, which is, therefore, not included in the general discussion of wounds.

Since infection depends on the chance of floating spores landing on exposed wood under conditions favorable for germination and final establishment, the bearing of wounds on ultimate infection is characterized by the relative surface of wood exposed, either in single large wounds or in a multitude of smaller ones, by the length of time the wound remains open before it is healed over, and by the character of the exposed wood as a suitable medium for the fungus involved.

The great majority of wounds in aspen remain open for many years. This is largely due to the fact that most of the wounds consist of fire scars or bruises, both of which destroy or kill such extended portions of bark surface that healing by callus can only be a very slow process. This condition increases the cumulative risk of infections through these types of wounds. The longer they remain open the greater the chances that they will finally become infected.

Less than one-fifth of the wounds examined were healed, and apparently these were lesions of little consequence. In nine cases it was possible to determine the years in which the wounds originated and in which they were finally grown over. The periods covered in the healing process are as follows: 7, 13, 21, 24, 25, 25, 30, 30, and 48 years. All wounds large enough to cause immediate loss (direct cull) were still open, though some of these dated back 100 and even 150 years. It is apparent that quaking aspen heals at least its larger wounds very slowly and that lesions remain open to infection for an unusual length of time.

An analysis of the type of wounds (Table 1) shows plainly that infections are commonest for those wounds which either present a large open-wound surface, like fire scars and bruises from falling trees, or form a spore trap, like ingrown stubs and broken tops with their rough surface of splintered wood.

TABLE 1.—*Wounds in relation to infection and cull (exclusive of canker)*

Type of wound	Wounds		Number of resulting cull cases			Direct cull caused by wounds	Net cull from rot	
	Total	Infected	x	xx	xxx		Total merchantable volume	Total gross cull
	Number	*Per cent*				*Cubic feet*	*Per cent*	*Per cent*
Open wounds:								
Fire scars	83	88.0	11	20	26	7.38	14.5	68.0
Bruises	55	32.7	4	1	2	.07	.34	1.6
Dead and broken tops	27	18.5			1		.30	1.4
Dead forks	3	0						
Ingrown stubs	10	60.0	2	1		.04	.10	.48
Frost cracks	12	16.0						
Lightning	2	0						
Miscellaneous	8	0						
Undetermined	10	20.0						
Total	210	50.5	17	22	29	7.49	15.2	71.5
Healed wounds:								
Fire	14	57.1	3				.02	.12
Bruises	8	12.5						
Miscellaneous and undetermined	23	34.7	2	1	1		.08	.39
Total	45	37.8	5	1	1		.10	.51
Open and healed wounds combined	255	48.2	22	23	30	7.49	15.3	72.0

The 240 trees examined had altogether 255 open and closed wounds which led to 126 infections; that is, about 50 per cent of the wounds became infected. Not all infections are of a serious nature, but 75, or 60 per cent, led to cull. Of these 75 cases of cull, 70 per cent present heavy loss (xx and xxx), while 30 per cent are still in the initial stages. The decay (net cull) coming from infections through wounds, open and healed, amounts to over 15 per cent of the total merchantable volume of the trees analyzed. The actual loss (direct cull) due to the wounds themselves is very slight, a little over one-half of 1 per cent of the total merchantable volume. Open wounds have an infection rate of 51 per cent as compared with 38 per cent for healed wounds, and their cull rate is very high. Decay traceable to open wounds amounts to 15 per cent of the total merchantable volume. Healed wounds led to only negligible loss.

Fire is beyond comparison the most frequent and the most consequential of all the many causes of open wounds found in aspen. For a clear understanding of the rôle of forest fires it is necessary to note that the area studied has not suffered much, relatively, from fires, although in no decade of the nineteenth century has it been entirely exempt from burns. The fire damage is practically on a par with that prevailing throughout the aspen stands in central Utah. Aspen is a short-lived species, so that the oldest record from the area does not go back farther than 1771. The only severe fire of the nineteenth century occurred in 1867. The seventies, eighties, and nineties each had occasional light fires. A single scar dates from 1903.

Only the younger age classes are practically free from fire wounds. They have grown up since the last serious fire occurred in 1867. For purposes of analysis, the open fire wounds are roughly graded according to their size, their depth, and the effect they are likely to have on the physiology and mechanical strength of the tree. The cases of cull to which the infections lead are similarly rated according to their importance. Even of the small fire scars over 76 per cent are infected. Larger scars are infected at the rate of 88 per cent and the largest at the rate of 108 per cent. Occasionally a single large fire scar gives rise to more than one infection.

The infections originating from fire scars are likely to be of an injurious nature, as will be seen from the following tabulation:

Infections starting from small fire scars:
- 46 per cent lead to cull;
- 38.5 per cent lead to heavy cull.

Infections from medium-sized fire scars:
- 78.5 per cent lead to cull;
- 54 per cent lead to heavy cull.

Infections from large fire scars:
- 84.5 per cent lead to cull;
- 81 per cent lead to heavy cull.

In other words, the greater the injury to the tree from fire the more cull, and the more serious cull, results.

The amount of cull due to decay entering through fire scars is closely related to the ages of the trees. The first loss from cull, one of 3.5 cubic feet, appears in the 71–80-year age class. The volume of cull increases slowly until in the 101–110-year class it suddenly rises to 14.5 cubic feet. For the next age classes, 111–120 and 121–130, cull volumes of 56.5 and [illegible]2 cubic feet, respectively, are recorded. The total cull from decay traceable to fire scars amounts to nearly 180 cubic feet, or 14.5 per cent of the total merchantable volume (see Table 1). It represents 68 per cent of the total loss from gross cull. The direct loss chargeable to the scars themselves amounts to only 2.8 per cent of the total gross cull, a negligible quantity when compared with the indirect loss resulting from infection and decay starting in fire scars. The extremely high cull per cent bound up with the physical presence of fire scars confirms and emphasizes the findings of similar detailed analyses of white fir and incense cedar. The indirect damage caused by forest fires is far greater than appears at first glance.

Fire is a more or less controllable factor in forest management. The extraordinary sensitiveness of the thin-barked aspen to fire injury and the great danger of the trees becoming infected through fire wounds make it imperative that aspen be protected even from light fires.

Next to fire scars in frequency of occurrence are bruises caused by falling trees and limbs. The thin bark of aspen renders the species particularly liable to wounding from this source, but the infection rate lags far behind that of fire wounds. A bruise is superficial and at most exposes only the sapwood. The underlying heartwood is protected from infection with the most destructive fungi until the cover of sapwood begins to check badly and finally disintegrates. Bruises are commonly infected, but only in rare cases does the infection lead to actual loss. Dead and broken tops show a surprisingly low infection rate, and such infections rarely result in cull. The highest infection rate, after that of fire scars, is found in "ingrown stubs," that is, broken-off and partly overgrown remnants of limbs and forks in the lower part of the bole; but as a source of cull the infections are negligible. Lightning seems to injure quaking aspen only rarely. Not more than two lightning scars were found in the area studied, and neither became infected. Smaller wounds of various origin were not infrequently accompanied by secondary decays, which have no bearing on the loss factor.

Of all infections, those by *Fomes igniarius*, the most energetic destroyer of the wood of aspen, are by far the commonest. About one-third of these enter through fire wounds, one-third through bruises and cankers, and the rest through knots, roots, and minor wounds. In practically all cases, stringy butt rot entered through fire scars.

RÔLE OF CANKER

The frequency with which canker occurs in Utah made it desirable to determine in detail the rôle played by this injury in the pathology of aspen. (Table 2.)

In so far as it exposes the wood, canker would be comparable to a wound, in the current sense of the word, were it not for one fundamental difference. A wound presents the largest surface of unprotected wood immediately after it comes into being. From that time on, callus formation in the natural healing process tends to cover up the exposed surface until the wound is closed. The chances of infection are on the decrease until they cease to exist with the healing of the wound. Canker, on the contrary, increases in size with age, owing to the successive killing back of the calluses as they are formed. The risk of infection is cumulative. Only occasionally is a smaller canker healed over. (Table 2, columns 4, 5, and 6.)

TABLE 2.—*Number of cankers and relation to infection*

Age class	Number of trees (basis)	Percentage of trees with canker	Type of cankers: Small	Type of cankers: Medium	Type of cankers: Large	Direct cull from canker	Cull from rot entering through canker
			Number	*Number*	*Number*	*Cubic feet*	*Cubic feet*
30–40 years	15	13	2	1	----	----	----
41–50 years	20	5	----	1	----	----	----
51–60 years	33	18	7	(1)	4	0.74	2.39
61–70 years	12	25	3	2	6	3.00	----
71–80 years	31	13	(2)	2	----	----	----
81–90 years	35	31	(3)	9	8	11.65	.30
91–100 years	21	38	3	8	8	.91	6.03
101–110 years	20	30	(4)	6	1	----	1.83
111–120 years	22	41	(5)	7	1	.15	.07
121–130 years	14	36	6	6	7	4.46	16.04
131–140 years	7	57	4	4	3	7.24	----
141–168 years	10	40	(6)	3	5	----	----
Total	240	26	(7)	(8)	(9)	28.15	20.00

[1] 5 open, 1 healed.
[2] 2 open, 1 healed.
[3] 1 healed.
[4] 4 open, 2 healed.
[5] 4 open, 1 healed.
[6] 1 healed.
[7] 35 open, 6 healed.
[8] 51 open, 1 healed.
[9] 43 open.

Beyond generalities little is known regarding the occurrence of cankers. On the area investigated, 63 trees out of a total of 240 had 139 cankers, of which 132 were open and only 7 healed. The direct cull caused by the cankers themselves amounts to a little over 2 per cent of the total merchantable volume, or a little over 10 per cent of the total gross cull. The latter relation classes canker as a far less negligible type of injury than fire scars.

On the other hand, out of 139 cankers only 26 became infected, and while these led to 11 cases of cull, not more than 6 resulted in serious decay. The entire net cull from rot traceable to canker amounts to only a little over 2 per cent of the total merchantable volume, or 10 per cent of the total gross cull—about the same as the direct cull from canker. Considering the apparently very favorable conditions for infection as presented in the aggregate by the relatively large surface of exposed wood in cankers, these figures are surprisingly low. It is not impossible that the peculiarly stained and brittle wood often underlying the cankers presents an uncongenial medium for the fungi attacking aspen.

An analysis of columns 1 and 3 of Table 2 indicates that the occurrence of canker is not so much a matter of age as of size of the trees. Every age is subject to canker, but the percentage of trees attacked increases with some regularity with increasing age. Canker is rarely a cause of top killing in large trees. Only three such cases were observed.

From the foregoing it appears that canker is not an important factor as an indirect cause of decay. Its rôle in the pathology of aspen reduces itself to many partial girdlings on bole, branches, and twigs and to the increased difficulty of barking in utilization for pulp; but these items are collectively of sufficient weight to warrant further and more intensive studies of the origin and life history of canker with a view to possible control.

RELATION OF CULL TO VIGOR OF TREE GROWTH

Former studies in white fir had indicated that the loss from injurious factors was not independent of the vigor of tree growth as expressed by the relation of the tree volume to the standard volume for the same age (see p. 10). In Table 3 the trees are segregated and tabulated in 10-year age classes according to their relative volume. For this purpose only those trees which deviate considerably from the standard are considered. Trees a little above or below are evidently too close to standard to be maintained in separate groups. Though this procedure leaves only small bases for the individual age classes, they are sufficiently large to indicate certain tendencies and relations. The net cull per cents due to rot do not increase steadily with age. There is a marked and sudden jump, which occurs for the trees much above standard in the 101–110-year age class, but for those much below standard, 10 years earlier in life. The same relation is reflected in the total net cull (last column) from all causes, though it is somewhat disturbed by the canker figures. In Table 3 the main sources of cull are listed separately. *Fomes igniarius* (F. i.) stands out as the most important individual factor. *F. applanatus* (?) and secondary fungi seem to find in quaking aspen only a moderately congenial host.

TABLE 3.—*Net cull per cents of total merchantable volume in 10-year age classes*

TREES MUCH ABOVE STANDARD

Age class	Number of trees (basis)	Net cull (per cent)						
		From rot				From canker	Misc.[4]	Total
		F. i.[1]	F. a.?[2]	Sec.[3]	Total			
Years:								
30–40	4							
41–50								
51–60	13	6.14			6.14	1.84	0.05	8.03
61–70	4					12.50		12.50
71–80	6	.42	3.25		3.67		.10	3.77
81–90	11	1.42			1.42		.10	1.52
91–100	3	2.46			2.46		.35	2.81
101–110	3	10.82	11.61		22.43		.66	23.08
111–120	7	37.10	4.53		41.63		.79	42.42
121–130	4	39.10			39.10		.94	40.04
131–140	3	4.67			4.67		1.27	5.94
141–168								

TREES MUCH BELOW STANDARD

Age class	Number of trees (basis)	F. i.[1]	F. a.?[2]	Sec.[3]	Total	From canker	Misc.[4]	Total
Years:								
30–40	2	23.82			23.82		1.59	25.41
41–50	13							
51–60	17							
61–70	4					0.94		.94
71–80	21	1.28	3.94		5.22		.01	5.23
81–90	16	2.09	.72	3.95	6.76	2.90	.48	10.14
91–100	9	16.46	6.21	8.09	30.76	1.87	.20	32.83
101–110	12	9.32	3.62	.21	13.15		.18	13.33
111–120	5	13.78			13.78	1.16	1.01	15.95
121–130	5	26.69			26.69	4.58	.24	31.51
131–140	4	17.44			17.44	14.51		31.95
141–168	2	24.70	13.27	.05	38.02		8.98	47.00

[1] F. i.=*Fomes igniarius.*
[2] F. a.? Stringy butt rot (*Fomes applanatus?*).
[3] Sec. Secondary fungi.
[4] Misc. Direct cull from fire scars, frost cracks, incidental wounds, etc.

CULL PER CENTS

The preceding sections deal with the analysis of the injurious factors active in aspen and their mutual relations and lead to an understanding of the processes which in the end result in economic loss.

Table 4 expresses this economic loss as gross cull computed for each 10-year age class. The total apparent merchantable volume of all trees cut is 1,237.3 cubic feet. The total volume of gross cull is 264.6 cubic feet, or 21.4 per cent. In other words, in cutting aspen for pulp in the unmanaged forest on types corresponding to that of the region studied, a general allowance of 21 per cent must be made for cull from all causes. Of this cull by far the greatest amount, or more than 18 per cent, is directly traceable to rot. Canker follows next, with only 2.25 per cent, and miscellaneous causes for cull, such as fire scars, wounds from falling trees, etc., are accountable for less than 1 per cent.

The basis of trees arranged in 10-year age classes is rather weak from 131 years on. The last group, 141–168, is supported by only 10 trees scattered over 27 years. The cull per cent from all causes for the well-supported age classes from 30 to 130 years reaches 21, thus hardly differing from the cull per cent of all ages up to 168.

TABLE 4.—*Cull per cents in 10-year age classes with gross cull charged to all causes of cull*

[Miscellaneous gross cull includes the direct cull from fire scars, frost cracks, incidental wounds, etc.]

Age class	Number of trees (basis)	Total merchantable volume	Gross cull							
			From rot		From canker		Miscellaneous		Total	
			Volume	Percentage of merchantable volume	Volume	Percentage of merchantable volume	Volume	Percentage of merchantable volume	Volume	Percentage of merchantable volume
		Cu. ft.	*Cu. ft.*		*Cu. ft.*		*Cu. ft.*		*Cu. ft.*	
30–40 years	15	10.32	0.14	1.36			0.01	0.09	0.15	1.45
41–50 years	20	12.82								
51–60 years	33	52.78	2.47	4.68	0.74	1.40	.02	.04	3.23	6.12
61–70 years	12	36.05	2.11	5.86	3.00	8.33	.02	.06	5.13	14.23
71–80 years	31	65.13	3.65	5.60			.10	.16	3.75	5.76
81–90 years	35	173.79	5.23	3.02	11.38	6.55	.28	.16	16.89	9.73
91–100 years	21	118.89	13.64	11.48	.91	.77	.33	.28	14.88	12.53
101–110 years	20	116.11	21.01	18.11			.42	.36	21.43	18.47
111–120 years	22	214.03	56.68	26.49	.15	.07	1.93	.90	58.76	27.44
121–130 years	14	176.80	73.46	41.48	4.46	2.52	1.33	.75	79.25	44.75
131–140 years	7	88.04	9.07	10.30	7.24	8.23	2.62	2.98	18.93	21.50
141–168 years	10	172.46	38.80	22.51			3.31	1.92	42.20	24.46
Total	240	1,237.30		18.20		2.25		.84	264.60	21.38

The percentage of the gross cull from rot alone (Table 4, column 5) shows a steady increase which changes to a sudden rise with the 91–100-year age class and reaches over 41 per cent in the 121–130-year age class. A similar increase appears in the total gross cull per cents, though without the regularity of the increase in rot gross cull, influenced as they are by canker gross cull, a factor which has little to do with age. Both young and old trees are subject to canker attack, and, given the same size of canker, the smaller the bole the heavier the damage.

It is evident that the cull per cents do not apply to area but to merchantable volume alone and that they can be used only for stands composed more or less of the age classes here represented.

Since miscellaneous cull is a negligible factor and canker cull is not only erratic but evidently confined to definite regions and stands, the rot cull remains as the important and more or less uniformly applicable index of the relative soundness of aspen stands comparable to the one under investigation. When the representation of age classes in a given stand is known, the cull per cents for each age class can be used, due consideration being given to the modifying agencies discussed in the preceding sections.

DISCUSSION

The aspen problem in Utah resolves itself into the question whether the species is to be considered a weed tree, to be replaced as soon as feasible by more promising species, e. g. conifers, or whether it is to be put under management and regulation with a view to utilization for pulp wood. The choice depends on a number of considerations, prominent among which is the relation of cull to volume produced. If quaking aspen can be made to produce, in sustained yield, sound pulp wood in quantities sufficient to warrant harvesting at a profit, the mere fact that it is already on the ground will speak strongly in favor of retaining and fostering the species. Replacing large areas of one species with another, particularly on sites as little favorable relatively as those now occupied by aspen, is an enormous and very costly undertaking, fraught with many risks. It has been tried over and over again in Europe, where the practice, except in extreme cases, is now thoroughly discredited. Moreover, it would be rash to assume that the stands expected to take the place of aspen will be free from loss. To judge from the estimated cull per cent in neighboring coniferous forests, the loss from decay and other injurious factors in the new stands is likely to be considerable, particularly if the longer rotation that goes with management for saw timber is taken into account.

On the other hand, it will be futile to attempt the management of aspen for pulp wood unless the relation of loss to output is considered. The forester will be inclined to regard the loss as serious when it tends to offset the increment. At present the only agency likely to put aspen under management is the Government. As long as the Forest Service is not authorized to harvest timber on its own lands even when the cutting is imperative, the question will remain more or less academic. Timber on national forests can be cut only when a purchaser of stumpage is found, and the purchaser is not concerned with the rate of increment and its relation to the loss factor. He is solely interested in the question whether the amount of sound wood he can harvest from a given unit will pay for his operations and leave him an adequate profit. Loss to him means something entirely different from what it means to the professional forester, and his concepts will dominate at least in the immediate future.

HARVESTING VIRGIN TIMBER

Just where the future purchaser of aspen pulp wood will draw the line it is impossible to say. Too many factors enter into the equation. But the knowledge of the cull per cents will help him to weigh the loss against expected output from regions similar to the vicinity of the Great Basin Range Experiment Station.

The data on which this bulletin is based cover the age classes from 30 to 130 years. The ages above 130 years are too weakly represented to be of much value. The trees analyzed do not represent one extensive all-aged stand, but are selected from a number of smaller, more or less even-aged groups, so that each class in the cull per cent table (Table 4, last column) gives at least a clue as to what cull per cent might be expected in virgin uncared-for aspen.

EVEN-AGED UNITS

Up to 90 years the percentage of cull from all causes is so low that it can not seriously affect the final output, though the loss through canker may introduce a disturbing factor. The cull per cent in the 91–100-year age class amounts to 12.5, which is undoubtedly well within reason from the point of view of the prospective purchaser. The 101–110-year age class, with over 18 per cent, may still prove attractive, while the 27.5 per cent gross cull of the 111–120-year class probably exceeds the limit of allowable loss, at least on the less accessible logging chances. The almost 45 per cent gross cull of the 121–130-year age class will render logging altogether unprofitable, even on the most accessible areas.

MANY-AGED UNITS

Aspen logging units in Utah are frequently made up of numerous smaller even-aged stands, presenting conditions analogous to those prevailing in the region studied. The cull per cent as a whole computed for all ages between 30 and 130 amounts to 21 and is therefore hardly high enough to act as a prohibitive deterrent, except perhaps on less accessible areas and under unfavorable logging conditions.

The greater the representation of the older age classes on a logging unit the greater will be the resulting cull per cent, and vice versa, as will be seen by comparison of the figures in Table 5. The arrangement of the table is self-explanatory. The merchantable volumes and the gross cull volumes for the combined-age classes were added separately and the percentages computed. In the first part of Table 5 (younger age classes prevailing) the first group is composed of the age classes 30 to 80. It is not to be assumed that stands much younger than 30 years old will be utilized. The second part of Table 5 shows the cull per cents of stands composed of older trees only, from 130 years downward to 70 years.

TABLE 5.—*Gross cull per cents in relation to age classes represented in the stand*

Age classes	Cull per cent		Age classes	Cull per cent	
	Total gross	Gross, exclusive of canker		Total gross	Gross, exclusive of canker
Younger age classes prevailing:			Older age classes prevailing:		
30-80	7	4	130-121	33	31
30-90	8	5	130-111	31	30
30-100	10	7	130-101	29	27
30-110	14	11	130-91	26	24
30-120	18	15	130-81	25	23
30-130	21	19	130-71	23	21

The desirability of a given tract depends, of course, not solely on a low cull per cent. Accessibility, quantity of merchantable timber per acre, and relative cost of handling small as compared with larger timber are important factors. But there can be no doubt that, other things being equal, a high representation of the younger age classes with their relatively small loss from cull will make a logging chance more attractive than a preponderance of the older classes.

The total gross cull is composed of cull from decay, cull from canker, and cull from miscellaneous causes. Of these three factors canker is the most erratic. It does not occur everywhere nor in equal intensity, and it is not directly progressive with age. Cull from decay, including miscellaneous causes, represents a far more stable factor. Although it would be going too far to assume that every stand of aspen, even if apparently similar to those in the region of the Great Basin Range Experiment Station, must show the same amount of decay per age class, it can be taken for granted that, over large areas, the variation in the cull from decay will not be considerable. Cull from miscellaneous causes, though also progressive with age, is only a minor factor, but the same causes that are at work on the area studied are present in other aspen forests. The last column of Table 5 illustrates the relation of cull from rot and miscellaneous causes to representation of ages in those stands in which canker is absent or rare.

It follows from the foregoing that, as far as the harvesting of virgin aspen is concerned, no working plan can be complete without a survey of available stands, both even aged and many aged, with regard to ages represented. The survey should take into account also the prevalence of canker, particularly in the younger age classes, where decay plays a minor rôle.

A survey of ages presents particular advantages in cruising timber for sale. The application of an arbitrary cull per cent to the cruise introduces gross errors, to the detriment of either the purchaser or the Government. Once the ages represented are known, it is an easy matter to determine, from the cull per cents per age class as given above, the actual relation of loss to output, within relatively narrow limits of error.

MANAGEMENT

So far the interests of the purchaser, not those of the professional forester, have been considered. The forester, not content with the disposal of existing virgin timber, is more deeply concerned with the establishment of improved stands and the perpetuation of maximum yield.

It is difficult to discuss questions of management and regulation when clear-cut definitions of both terms with relation to aspen, except in the abstract, are lacking. What form management will take in the aspen forest in the future, outside of fire protection, is open to guess. Improvement cutting on a large scale by means of timber sales—practically the only silvicultural practice now possible—is out of the question for aspen. It is more than probable that management in the aspen forests of Utah will consist in a first heavy utilization, followed by the slow establishment of adequately stocked even-aged or two-aged stands, which then may come under true management by a new generation of foresters. The present generation will, undoubtedly, have to deal with the wild, uninfluenced, unmanaged aspen stand, its protection and its utilization only. It will practice preservative rather than creative management. Nevertheless, the chances of success in the future depend on the measure of foresight and forethought bestowed to-day upon the aspen problem and the possibilities of constructive management.

The probable evolution of the management of aspen in Utah must follow the history of all conversions of virgin forests into managed forests and move in two successive steps: (1) The gradual replacement of the existing wild, highly defective, and many-aged forests by more or less even-aged second growth, uncared for except in so far as adequate fire protection decreases the number and size of fire scars and therewith the chances of infection (conversion or transition period), and (2) evolving progressively out of the conversion period final regulation on the principle of sustained yield together with systematic elimination of all controllable injurious factors.

Systematic and well-planned replacement of virgin timber by young growth is not possible on national forests under present conditions. Even sporadic replacement depends on the chance of finding a purchaser for a given block of timber; that is, it is incidental to a timber sale. The unit to be converted is not necessarily one of silvicultural choice. At best a compromise may be effected between pressing silvicultural needs and the contingency of disposing of existing timber by means of a timber sale. Thus the harvesting of virgin timber, which must precede management proper, is left more or less to chance.

NET VOLUME

Given the possibility of constructive action, the choice of the time at which the conversion should be inaugurated becomes a matter of consideration. From the point of view of economics as influenced by pathological factors, conversion should begin before loss becomes too heavy to make possible a timber sale, as the only means of conversion. What is left after the cutting represents the raw material for the next stand, and the infections present in the young growth are carried over into the conversion period. Figure 2 illustrates the progressive course of average decay volume and of average tree volume in 10-year age classes of a practically virgin stand, containing trees of all ages from 30 to 130 years. The age classes above 130 years are poorly represented and not of sufficient importance in so short-lived a species as quaking aspen to be included in the curves. The loss from canker likewise is not considered. Its bearing on the final output is of relatively small importance and must be judged separately in each case. From a practical point of view, neither the volume curve nor the decay-volume curve are relevant when taken individually. The volume curve regarded by itself is misleading, since it gives merely the apparent, not the true, merchantable volume. The decay-volume curve, on the other hand, may be ever so steep and reach ever so high, but in the final analysis the only criterion is the net volume, the difference between the apparent volume and the decay

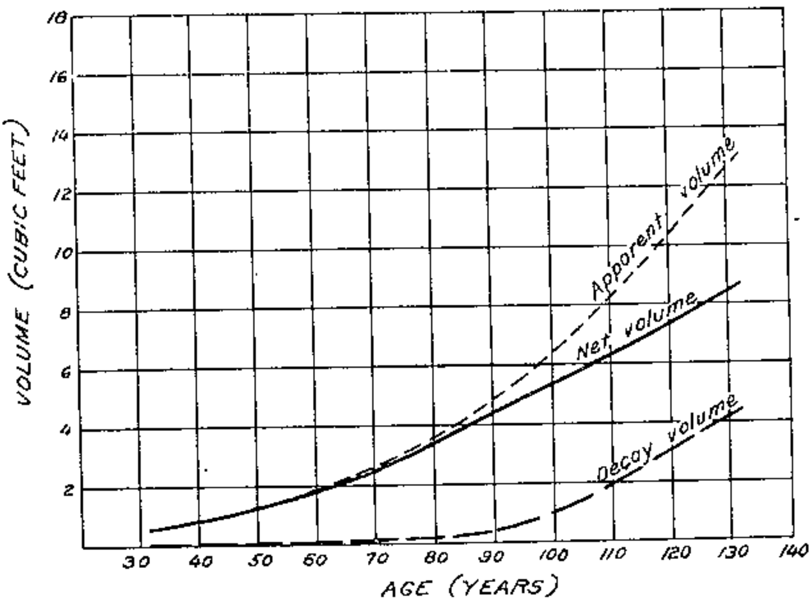

FIGURE 2.—Curves of apparent volume, decay volume, and net volume over age

volume. The net-volume curve makes it possible to gauge the actual amount of merchantable timber on the ground at given stages in the development of the stand. Following the apparent-volume curve fairly closely in the younger age classes, it begins to lag behind at about 90 years but still continues its upward trend.

NET INCREMENT

The actual ratio of decay volume to apparent volume is not the only consideration. Any attempt at regulation in the forest is futile without due regard to the rate of increment. Figure 3 illustrates the relationship between the apparent periodic increment and the periodic decay increment. Here again the criterion is the curve of net periodic increment; that is, of the difference between apparent periodic increment and periodic decay increment. The curve of apparent increment simply indicates the rate of increment for a hypothetically sound forest in which no loss at all occurs. The net-increment curve alone illustrates the actual profit over loss in 10-year periods. In the younger age classes the curve runs close to that of apparent increment. In the 70-80-year period it flattens out and thereafter remains practically at a level, far below the apparent-increment curve. From about 80 years upward there is no gain in net increment. The flattening of the apparent-increment curve occurs fully 40 years later, so that loss from decay brings about the same economic effect at 80 years which accompanies maturity and senility at 120 years.

When the representation of trees of different age classes is known, the net-volume curve affords a clue as to whether, at a certain time, the harvesting of a given stand will be profitable or not and serves

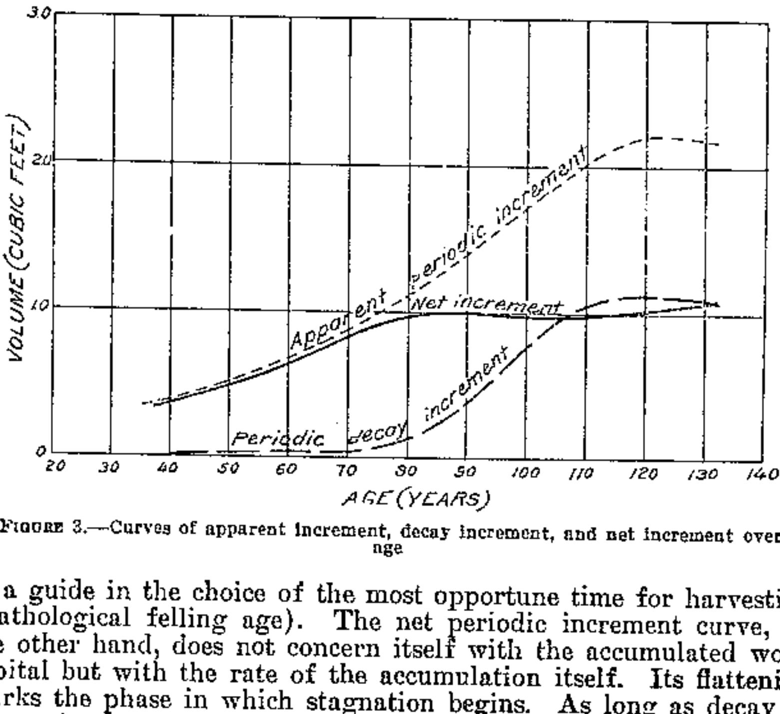

FIGURE 3.—Curves of apparent increment, decay increment, and net increment over age

as a guide in the choice of the most opportune time for harvesting (pathological felling age). The net periodic increment curve, on the other hand, does not concern itself with the accumulated wood capital but with the rate of the accumulation itself. Its flattening marks the phase in which stagnation begins. As long as decay in aspen plays a rôle similar to that it plays to-day—and it is not likely that during the conversion period a great change is to be expected—the culmination of the curve is the limiting factor which determines the pathological rotation.

It is the part of forest regulation to read from these curves just where the lower age limit for the interruption of the process should be placed and how long a given stand may be left uncut without undue loss. In managed forests the determination of the felling age and rotation are closely interrelated problems. When felling age and rotation are made the objects of speculation, such yield figures as may be obtainable are generally applied as though the loss factor did not exist. In the conversion of the virgin forest the felling age is the guiding factor, with rotation visualized in a far future.

Through the first cut the forest is brought into immediate touch with the generation or generations concerned with its management. For long-lived species this change in time relations reduces the perspective from centuries to a number of decades. Aspen is short lived. The life of the wild aspen forest as a whole does not reach much beyond 130 years, and if decay were absent that age might be chosen as the felling age for the first cut, though not for the rotation. The pathological rotation may be figured on a net maximum-volume basis or on the basis of rate of net increment. Both methods are closely related. They approach the same group of problems from different angles. In a former paper (*11, p. 59*) the writer has used the net maximum volume as the guiding factor, and Baker in his bulletin on aspen (*1, p. 15*) has placed the pathological rotation on the same principle at 110 years, following therein the data furnished in the writer's preliminary manuscript report. Weigle and Frothingham (*15, p. 31*) came to the conclusion that for aspen in the Northeast the maximum age the trees may be allowed to attain is fixed by the relatively early beginning of decay at approximately 80 years.

There are valid reasons for the use of the net maximum volume as a criterion for the choice of the pathological rotation. Its weakest point is that it is not sufficiently definite, at least for aspen. On the other hand, a strong case can be made for applying the rate of net increment. Here the evidence is clear and unmistakable.

The choice of both felling age and rotation is largely a matter of personal judgment and interpretation of data. In the following discussion the ratio between the net maximum volume and the rate of net increment is made the basis for the pathological felling age. For the pathological rotation the process is reversed. The rate of net increment is regarded as the decisive factor, due consideration being given to net maximum volume.

The steady rise of the net-volume curve in Figure 2 indicates that the accumulated net wood capital will support a logging operation at any time within the life of the stand, but the straightening out of the net-volume curve and its deviation from the apparent-volume curve makes it advisable to place the pathological felling age at about 80 to 90 years. The flattening of the net-increment curve (fig. 3) supports this view and limits the pathological rotation to about 80 to 90 years. Since it is not likely that longer rotations will be adopted for quaking aspen grown for pulp wood, the main conclusion is that the pathological factor in this species does not shorten either the felling age or the rotation to a point below that which is siliviculturally desirable.

In the wild forest of unknown history it is difficult to determine ages over large areas. The practical forester still works with diameters, not with age classes. In Figures 4 and 5 the same elements as in Figures 2 and 3 are presented on a d. b. h. basis. The curve of net merchantable volume, after a satisfactory rise in earlier years, tends to flatten out after the trees have reached 12 inches d. b. h. The flattening of the curve is marked at 14 inches d. b. h. In Figure 5 the curve of net increment in merchantable volume rises rapidly to about 9 inches d. b. h., culminates at about 10 inches d. b. h., and

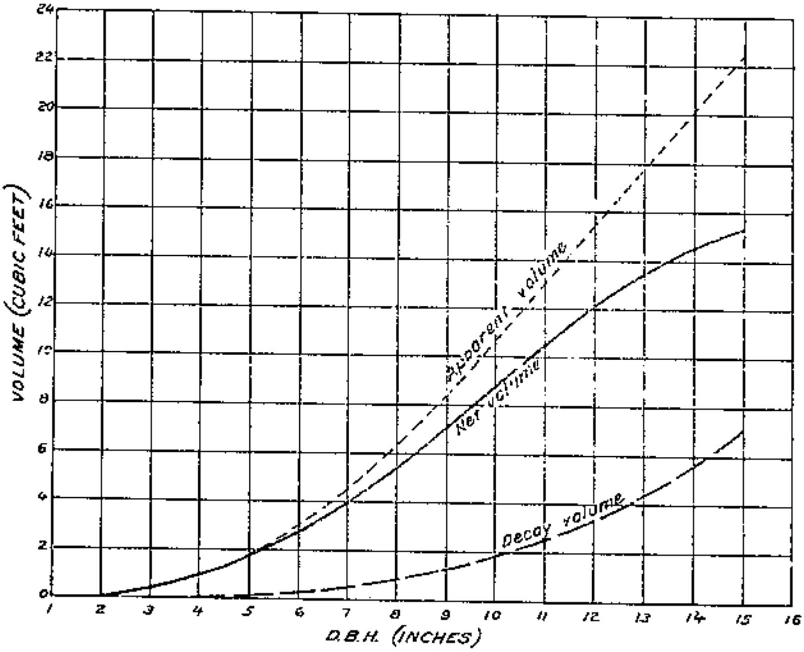

FIGURE 4.—Curves of apparent volume, decay volume, and net volume over d. b. h.

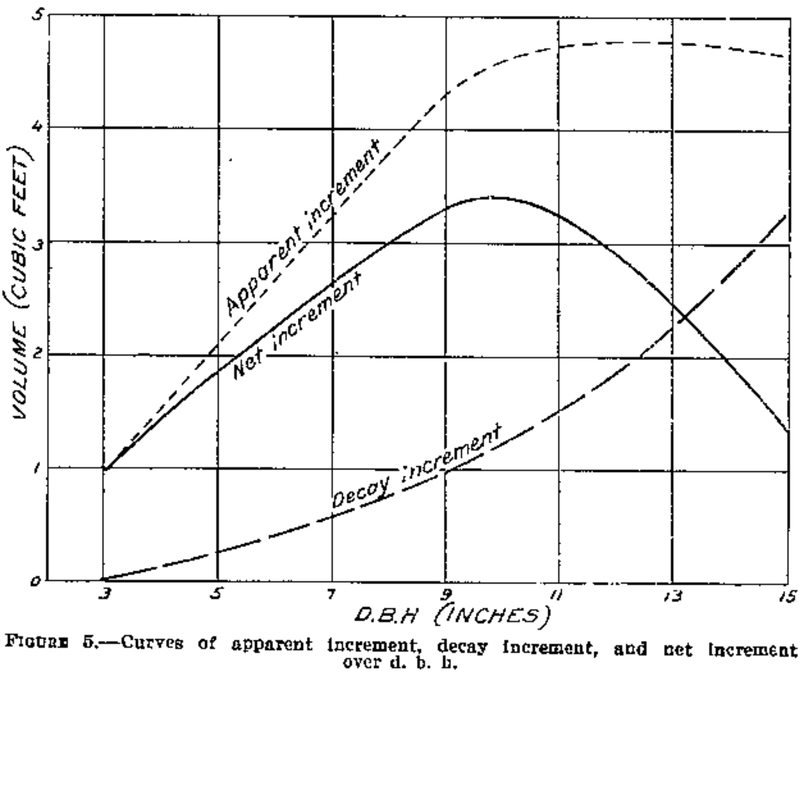

FIGURE 5.—Curves of apparent increment, decay increment, and net increment over d. b. h.

then drops almost in the same ratio. At 13 inches d. b. h. the net increment is not greater than it was at about 6.5 inches d. b. h. It is clear that in considerations of prospective yield the culmination of the curve at 10 inches d. b. h. offers an indication as to the management of a given stand, especially when judged in conjunction with the net-volume curve of Figure 4. On the basis of d. b. h., the pathological felling size—to coin a term corresponding to felling age—may be placed at about 12 inches. The pathological rotation is determined by the culmination of the net-increment curve at 10 inches d. b. h. While diameter is, broadly speaking, a function of age, the relation is too erratic to be reliable. Curves based on diameters can therefore serve only as a makeshift for use in questions of regulation.

It is here taken for granted that management of aspen is contemplated on the better sites, I and I–II, only. On poor sites aspen makes very slow and poor growth and reaches merchantable size at an age when the loss from cull is unduly high. The influence of growth has been illustrated by Table 3. Vigorous growth retards heavy loss by at least a decade. At best, aspen in Utah, even on the better sites, does not produce timber in such quantities that the loss factor can be disregarded in any scheme of management. The question is rather whether by proper management, including choice of sites, the loss can be minimized to such a degree that it does not make utilization unprofitable.

THE CONVERSION PERIOD

For the purposes of discussing the probable rôle of pathological factors in the conversion period, the outstanding results presented in the preceding pages are here summarized.

The principal direct causes of cull in aspen are decay (mostly from *Fomes igniarius*) and canker, or a combination of both. Cull caused by wood-boring insects does not lie within the scope of this study. Other causes of cull, such as fire scars, frost cracks, wind shake, and lightning scars, which are to be reckoned with in species of the saw-timber type, are practically negligible in pulp-wood timber. But as an indirect cause of cull one of these, fire scars, can not be overlooked. By far the greater part of cull has to be charged to decay, and much of this enters through fire scars, so that the latter are responsible not only for the direct loss from burning but for the indirect far greater loss from decay. The rate of infection of fire scars, even of smaller size, is very high, and the infections readily lead to heavy cull. There is a direct relation between number and size of fire scars and cull from decay. To a small degree, infection of the tree takes place through open cankers, and to an even smaller degree through bruises from falling trees.

Fires and fire scars are preventable to a certain degree. The elimination of fires will undoubtedly cut down cull from decay to a considerable extent. Canker can not be controlled until more is known about its cause. Bruises from falling trees and limbs not only induce decay but also stand in an indirect relation to the decay factor in so far as butt and root rots mechanically weaken the affected trees to such an extent that they are easily thrown over in heavy windstorms. When decay, coming from the bole, destroys the central wood cylinder of a larger limb, the thin shell of sapwood and bark is no longer able to carry the weight, and the limb breaks off. The elimination of decay in a stand necessarily cuts down windfall to a large extent and therewith the bruising of standing timber.

The occurrence of decay depends largely upon the number, size, and character of the wounds present, while the degree of decay depends partly upon the character of the wounds through which it enters, partly upon the age of the trees and their rate of growth, and finally upon the combination of these factors. Age is beyond doubt the most important. Decay is rare in the younger age classes and increases with age. From a certain age class onward decay becomes prevalent and later cuts heavily into the timber values produced. Canker, a minor factor, is not progressive with age in the same sense as decay.

With these facts in mind it will be possible to discuss the probable rôle of pathologic factors in the management of the future aspen forest.

As long as forest management is limited to relative, not absolute, protection from fire, to the slow harvesting of existing stands, and to the creation of second-growth, but wild, uncared-for stands necessarily partaking of the nature of the virgin forests they replace, the same losses must be expected during the conversion period, except that decay traceable to fire scars will decrease in the proportion in which fire-scarred individuals drop out and in which fire itself is kept out of the forests.

It will be a long time before all virgin aspen forests, even on the better sites, are fully and absolutely protected from fire. It is logical to assume, therefore, that for many years, at least, a large acreage will present conditions similar to those under which the existing stands have grown up. For these aspen forests the cull per cents determined from Table 5, their relation to relative volume growth (Table 3), and the effect of a combination of age, relative growth, and wounding, give at least a clue as to the proper time for disposal, depending on what is considered as serious loss from cull.

It may be argued that, since the prevention of forest fires will automatically reduce rot in standing trees to a minimum, decay will no longer constitute a limiting factor, even in the higher age classes. If this were correct, loss from decay would be unknown in those intensively managed forests of Europe from which fires are practically excluded. It is true that in European forests under the most perfect type of management such losses as are of common occurrence in this country are unknown; yet no forest in Europe is free from decay and cull. Intensive cultivation is the consequence of high valuation of timber, and the more valuable the product the more detrimental are losses which in less valuable timber would be completely overlooked. Thus, what in the present study is considered as minor or even negligible cull, rises to the rank of serious loss with the rise in value of the timber itself. The general trend in the valuation of all commercial timber is upward, and the change is particularly noticeable in this country with regard to a number of so-called inferior species, which not long ago were not cut at all, but which now find a ready market.

Aspen in Utah, if ever it moves up into the rank of a profitable source for pulp wood, will not escape the general tendency. As a necessary corollary the loss factor will be increasingly emphasized, and the minor decays, cankers, etc., which now are hardly noticed, must command relatively the same attention that is given to-day to heavy rot coming in through fire scars. If this reasoning is correct, it may be assumed that in the future much lower cull per cents will exert a limiting influence in the determination of the felling age.

FINAL REGULATION

Unless management culminates in regulation through control of the injurious factors which have caused the defective condition of present stands, the new growth will revert to the same virgin defective type.

Intelligent control of detrimental factors, whether influencing the increment or destroying actual wood values, characterizes the progress from the first steps in conversion to final regulation. Regulation aims at the greatest possible production of high-grade timber per unit in sustained yield, a goal that is unattainable unless at the same time those injurious elements are kept in check that either affect the increment or cause loss in the form of cull.

Fortunately the most prominent of all factors connected with cull, namely age, is subject to control through the choice of rotation. A very short rotation would reduce cull to a negligible figure, but at the expense of remunerative volume production. Since absolute control of all cull factors is impossible, sane regulation will attempt to strike a balance between highest possible volume production and unavoidable but not economically prohibitive loss.

The first effect of regulation must show itself in the decrease of the number of slow-growing, suppressed, and wounded trees, so that the combination of these factors gradually becomes less frequent.

CONTROL OF INJURIOUS FACTORS

That well-planned and judicially executed control measures can very materially improve aspen forests is undoubtedly true. The most urgent control measures, next to prevention of fires and adjustment of the age factor through rational determination of felling age and rotation, must be the periodic cleaning of the forest by elimination of the sources of infection, on one hand, and of individual trees most subject to infection, on the other. It should go without saying that trees with evident infection, especially those with sporophores of wood-destroying fungi, have no place in the regulated forest.

In this connection attention is called to infected aspen stumps, snags, and windfall. Both *Fomes igniarius* and *F. applanatus* are capable of living saprophytically on dead aspen wood and roots. They find favorable conditions for development and fruiting in stumps and dead trees, from which infection may spread to hitherto sound neighboring individuals. Impossible as the grubbing of aspen stumps appears at present, the protection of commercially valuable stands may ultimately necessitate the practice in the future. Meanwhile insistence upon cutting to low stump heights will reduce to a minimum the wood mass available for saprophytic growth. Offal resulting from control work, such as stumps, windfall, scraps, and infected wood, should not be permitted to remain lying in the woods. All such material should be destroyed by burning.

In control measures of this type the size of the unit treated influences their effectiveness, at least with respect to sporophores. The disposal of stumps, snags, and windfall is a protective measure which immediately benefits even the smallest stand. It eliminates an abundant source of direct infection of neighboring trees and clears the ground for young trees. To destroy sporophores or even sporophore-bearing trees on small areas, however, except as a matter of principle and routine, is not worth the trouble and expense. Spores are extremely small and light and are carried by air currents for long distances. For this reason the systematic eradication of sporophores can be advocated only when large areas are taken under treatment. The number of spores liberated from a single sporophore is immense, and a thorough plugging of this main source of infection over a large area could not but have a beneficial effect. But since it is impossible to extend the practice over all aspen stands, including those on poorer sites, the eradication of sporophores on the area treated is not equivalent to eradication of all spores which might be carried in from the outside. The danger of infection is materially lessened, but not totally absent, just as in insect control an epidemic is materially reduced without absolute extinction of all individuals.

Effective improvement, therefore, must include the removal of trees with wounds of a character likely to become infected. Here fire scars stand in the first line. The larger and deeper the scar the more imperative is the removal of the tree. Large bruises follow next. They are to be rated below small fire scars. Trees with large cankers on the boles should not be tolerated. Even small cankers on limbs, while not immediately impairing merchantability, affect the increment and are likely to spread to the boles. Intensive control may in some cases even have to resort to the pruning of cankered limbs.

Listing control measures in the regulated forest in accordance with their relative importance, the elimination of infected living and dead trees comes first, then that of wounded trees, and finally that of cankered trees and limbs.

It is not likely that frequent improvement thinnings will be practiced in aspen forests. Where only one or two such thinnings are contemplated during the life of the stand, the length of the period likely to elapse between the act of cleaning and final utilization governs the relative urgency of the control measures. The longer a wound remains open the greater is the chance of its becoming infected, so that the probability of infection steadily decreases with the approach of the final cut. The elimination of wounded trees is, therefore, more immediately urgent in the earlier than in the later part of the life of the stand, due weight being given to the size and character of the wounds. Trees already so badly infected that the symptoms of decay are readily detected should, as a matter of course, be cut at any time, but in view of the fact that increasing age strongly aggravates the decay factor, it would be a singular mistake to leave infected trees in older stands uncut on account of utilization drawing near. The older and bulkier the trees, the greater is the probability that in the remaining years decay will destroy considerable volumes of potentially merchantable timber.

In the control of canker and the cutting of trees with bruises, the age factor must equally be taken into account. In certain cases the combination of two or more minor injuries on the same tree—as, for example, a smaller fire scar and canker on the bole—will stamp the individual as undesirable in the regulated forest.

SUMMARY

Quaking aspen covers large areas of the national forests in Utah. At the present time it finds practically no use as a timber tree. The problem presents itself whether aspen should be replaced by more promising species or placed under management for possible utilization as pulp wood. Management involves protection and gradual replacement of the present wild forests by second growth, looking toward regulation. Replacement is possible only through utilization of old growth and is dependent upon the chances for timber sales. For timber sales the cull per cent to be charged against the apparent volume must be known.

The present study covered a representative area located at an elevation of 8,750 feet near the Great Basin Range Experiment Station in the Wasatch Range of the Rocky Mountains.

Cull is low in the younger age classes and increases with age, at first slowly, until in the 91–100-year age class a sudden and marked increase occurs. Relative vigor of growth, expressed in the relation of the tree volume to standard volume for the same age, exerts a modifying influence. In trees above standard the marked increase takes place in the 101–110-year age class; in those below standard, 10 years earlier. Cull from decay depends largely upon size and character of wounds. About 50 per cent of the wounds become infected. Fire scars are the most important type of wounds. They commonly lead to infection and heavy cull. The total cull from decay traceable to fire scars amounts to almost 15 per cent of the total merchantable volume and represents 68 per cent of the total loss from gross cull. A common canker of unknown origin unfavorably influences the increment and distorts the boles. Of 240 trees analyzed, 63 had in the aggregate 139 cankers, of which only 26 were infected. Of these infections only 6 led to considerable cull.

The merchantability of a given stand depends partly upon apparent volume, accessibility of the stand, and logging facilities, and partly upon the cull per cent to be deducted from the apparent volume. What will constitute a permissible cull per cent in a given case is a matter of judgment. The general cull per cent for the area studied, representing approximately Site I–II and comprising ages from 30 to 130 years, is 21 per cent, largely consisting of decay from *Fomes igniarius*. The age class 101–110 years has a cull of 18.5 per cent; the class 111–120, 27.5 per cent; and 121–130, 45 per cent. It is recommended that existing stands to be offered for sale be surveyed with regard to age, since cull bears a direct relation to age. After the improvement of a given unit through timber sales and after the establishment of second growth, the elimination of fires—and therewith of fire scars—will contribute largely to the lowering of the cull per cent due to decay; but with increase in the valuation of the timber itself, discrimination against minor cull will also become intensified.

Unless management culminates in regulation through control of the injurious factors which have caused the defective condition of present stands, the new growth will revert to the same virgin defec-

tive type. Regulation is the process of converting the defective virgin forest into the improved, cultivated forest. Final regulation requires active control of injurious factors through elimination of infected trees as sources of infection and of trees most likely to become infected on account of wounding.

On the basis of net volume production and net increment, both the pathological felling age and the pathological rotation lie at about 80 to 90 years. From the point of view of economics as influenced by pathological factors, it appears possible to raise quaking aspen in the intermountain district for pulp, because the silvicultural rotation will in all probability be shorter than the pathological rotation.

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