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With Special Reference to Forest Management in Minnesota

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ILLUSTRATIONS

The writers are greatly indebted to R. M. Brown for valuable assistance in connection with the compilation of the data; to E. M. Freeman, chief of the Division of Plant Pathology and Botany, University of Minnesota, and to Raphael Zon, Director of the Lake States Forest Experiment Station, United States Forest Service, for advice and assistance throughout the course of this study.

HEARTROT OF ASPEN

WITH SPECIAL REFERENCE TO FOREST MANAGEMENT IN MINNESOTA

By HENRY SCHMITZ and LYLE W. R. JACKSON

INTRODUCTION

Aspen, or popple (*Populus tremuloides* Michx.), because of the wide area it now occupies, can be considered one of the most important tree species in Minnesota. Altho hardwoods originally occupied approximately only 1,500,000 acres, a comparatively small part of which was in aspen, it is estimated that approximately 50 per cent of the total forest area of the northern half of the state, or 10,000,000 acres, is now in aspen. Aspen will therefore play a very important part in any attempt at systematic management of forest lands in Minnesota for the production of wood crops.

Ecologically, the aspen type is usually regarded as temporary, but frequent fires tend to make it more nearly permanent. In its conquest of the better red and white pine soils in Minnesota, aspen has been materially assisted through unwise and unregulated cutting and through the injudicious use of fire. Obviously, then, whether or not the acreage now in aspen will increase or decrease in the future depends largely on the protection from fire which these areas receive and upon the silvicultural methods employed to convert aspen stands to those of a more valuable species. In certain regions and on certain limited areas, this conversion is taking place naturally, but future fires and unwise cutting methods can easily and quickly undo nature's efforts in this direction. Considering all the factors involved, there seems to be little likelihood that the aspen acreage in Minnesota will be materially reduced in the near future.

Unfortunately, there is a prejudice against the use of aspen wood, even for purposes for which it is well suited. This prejudice is due, to a considerable extent at least, to its susceptibility to heartrot, resulting as a rule in large losses, especially in the older trees.

It is important, therefore, that silvicultural practices and methods of management for these stands be worked out which will reduce the losses from decay to a minimum. The primary object of this study was to determine the extent of these losses and to furnish the pathological data necessary in devising a rational system of forestry to reduce them.[1]

[1] A comprehensive project, of which this study is only a part, dealing with the growth and yield of aspen in Minnesota, has been undertaken by the Cloquet Forest Experiment Station in co-operation with the Lake States Forest Experiment Station. The results will soon be ready for publication.

USES OF ASPEN

Little or no recent information is available concerning the amount of aspen used in Minnesota for different purposes. It is known generally that aspen is quite widely used for fence posts, to some extent for lumber, ties, box shooks, slack cooperage, excelsior, and paper pulp. Crocker[2] estimates that the annual consumption of aspen in Minnesota aggregates 105,592 cords. Of this amount, 20,000 cords are used in the manufacture of paper pulp.

It is safe to assume that its use will be more extensive in the future, altho aspen has certain characteristics that render it poorly adapted for certain uses. On the whole it is available only in comparatively small sizes. The wood is fairly soft, weak, and warps badly in seasoning. Furthermore, the wood lacks durability, a condition which ordinarily renders it unfit for fence posts, ties, and similar uses when it must come in contact with the soil. This disadvantage can be largely offset by treating with a wood preservative. It is a significant fact that one large Canadian railroad system has used treated aspen ties, and, so far as the writers are able to ascertain, has been fairly well satisfied with the results. Should the demand for aspen ties increase, it would create a good market for the larger sized material.

Aspen is also used in the manufacture of excelsior. No data are available to show how much is used for this purpose, but it is undoubtedly considerable. There is no reason why the use for this purpose should not increase.

The use of aspen in the manufacture of wooden boxes in Minnesota is also probably greatly on the increase. In 1913 it was estimated that 360,000 board feet was used;[3] in 1926, one boxboard mill alone cut more than twice this amount in a single month.

Aspen is also quite extensively used for barn floors and in rough farm buildings. If properly seasoned and kept dry, apparently no great difficulty is experienced with its use for these purposes.

CAUSES OF DECAY IN ASPEN

In general, three fungi are usually considered to be the cause of most of the decay of aspen heartwood. All are extensively distributed in both the eastern and the western hemispheres. The most important of these organisms is *Fomes igniarius* (L.) Gillett, which is common throughout the entire range of aspen and everywhere causes heavy losses. Considerably less important is *Armillaria mellea* Vahl., which

[2] Crocker, D. A. Pulpwood in the Lake States. Woodlands Section, American Pulp and Paper Association, Bull. 3. New York. 1926.

[3] Maxwell, H. U. Harris, John T., and Cox, Wm. T. Wood-using industries of Minnesota. St. Paul. 1913.

commonly causes a root rot of many deciduous and coniferous trees, but which may also cause butt rot in aspen as well as in other trees. Whether *Fomes applanatus* Fries. is more important or less important than *Armillaria mellea* as a cause of heart rot or butt rot in aspen is a matter of conjecture. Meinecke[4] considers *Fomes applanatus* second in importance to *Fomes igniarius*. He also found that in Utah *Fomes applanatus* seems to be confined to the butt of the tree, and therefore rarely becomes economically important, tho it may be locally destructive. On the other hand, Eklund and Wennmark[5] find *Armillaria mellea* to be the cause of an important heartrot and butt rot of *Populus tremula* in Sweden.

There is reason to believe that *Fomes igniarius* is responsible for most of the loss due to decay of aspen in Minnesota. In the course of this study, no fruiting bodies of *Fomes applanatus* were found, and only in two instances were fruiting bodies of *Armillaria mellea* found. In both of these cases the two affected trees also bore numerous fruiting bodies of *Fomes igniarius*. The comparatively rare occurrence of sporophores of *Fomes applanatus* and *Armillaria mellea* does not necessarily mean that they do not cause considerable decay in aspen.

Minnesota is not unlike many other regions with respect to the damage caused to aspen by *Fomes igniarius*. For example, Cameron[6] found that around Lesser Slave Lake, in Canada, at least 50 per cent of the aspen is without commercial value, owing to attacks of *Fomes igniarius*. Von Schrenk and Spaulding[7] likewise point out that in New England, as well as in Colorado and New Mexico, it is almost impossible to find healthy stands of aspen which have attained any appreciable age because of the extreme destruction brought about by this fungus.

For practical purposes then, *Fomes igniarius* may be regarded as the primary cause of heartrot of aspen in Minnesota. This is done, fully recognizing the fact that other fungi may be of greater importance in this connection than we have been able to determine in this study.

[4] Meinecke, E. P. Pathology of quaking aspen in relation to the management of the species in District 4. Unpublished manuscript.

[5] Eklund, S. and Wennmark, G. Några undersokninger av aspskog. Skogsvards Föreningens Tidskrift. 23:80-104. 1925.

[6] Cameron, D. R. Report on timber conditions around Lesser Slave Lake. Forestry Branch Bull 29. Ottawa, Canada. 1912.

[7] Schrenk, H. von and Spaulding, P. Diseases of deciduous forest trees. U. S. Dept. of Agr., Bur. Plant Indust., Bull. 149. 1909.

FIELD METHODS

That the results obtained from this study might be generally applicable to the entire aspen region, the sample plots for obtaining cull data were distributed throughout the commercial range of the tree in the state. Aspen occurs generally throughout the entire northern half of the state with the possible exception of the Red River Valley. Even there, aspen is one of the most common of forest trees, but nowhere in this particular region is it found in large quantities or in comparatively large sizes.

The results obtained in this study are based upon data from 385 sample trees selected from 77 sample plots one-tenth acre to one acre in area. About half of these plots were selected in fully-stocked stands, the rest in stands not fully stocked. The trees in fully-stocked stands from which the pathological data were obtained, were trees of average volume for the stand in question. The sample plots were distributed about equally in well stocked and understocked stands, because in all probability well stocked stands have never been touched by fire. Even a light ground fire causes considerable damage to aspen, killing many of the trees and causing numerous fire scars on many of those remaining. In general, fire scars are one of the most dangerous avenues of entrance for wood-destroying fungi.

No data are available to show the extent on an area basis to which present stands of aspen have been damaged by fire, but it is undoubtedly appreciable. It should be borne in mind, however, that not all of the understocked sample plots studied were understocked as a result of fire. In some cases the understocking was undoubtedly the result of poor sprouting or seeding or other factors.

On the average five sample trees were cut on each sample plot. As a rule, 3 of these were in the dominant crown class and one each in the intermediate and suppressed crown classes. This general procedure was not always strictly adhered to, as it was very difficult to recognize the different crown classes in both very young and old stands.

The sample trees were cut with a 1-foot stump and then further cut into 8-foot sections up to a 3-inch top. Whenever possible the age was determined on the stump. It was sometimes impossible to determine the age on the stump, on account of an advanced stage of decay. In these cases either the average age of the plot was taken, that is, the age of the other trees in question, or else the age was determined at the end of the first 8-foot section by adding five years to the age thus obtained.

The following data were taken on each sample plot on which sample trees were cut and studied:

- Location of plot
- Average age of trees on plot
- Site quality
- Associated species
- Character of soil
- Ground cover
- Brush
- Evidence of
  - Fires
  - Grazing
- Crown density
- Number of trees per plot
- Diameter breast high
- Total heights

The following data were obtained from each sample tree:

- Diameter breast high outside bark (to nearest 1/10 inch)
- Total height (to nearest foot)
- Age on stump
- Crown class
- Wounds
  - Mechanical
  - Fire
  - Insect
- Presence and number of sporophores
- External signs of decay
  - Persistent dead branches
  - Color of bark
  - Character of branch scars
  - Early production of furrowed bark
- Apparent avenue and height of infection
  - Branch scars
  - Insect scars
  - Fire scars
  - Root
- Causal organism

In Minnesota, it is the exceptional aspen tree that does not have a discolored heart. The intensity of the discoloration varies between wide limits and in general probably corresponds to different stages of decay. This coloration is not necessarily, however, always associated with decay and may be the result of either mechanical or insect injury.

In this study three stages of decay were arbitrarily distinguished—incipient, intermediate, and final. In incipient decay the wood is faintly colored from light pink to straw brown. The intermediate stage includes all degrees of coloration from straw to chocolate brown, but the wood is apparently still hard and firm. The final stage includes all soft, punky wood irrespective of color. The classification was limited to these three stages in order to allow an approximate determination of cull for certain industries utilizing aspen. For example, the excelsior industry apparently accepts and utilizes all sound, firm wood irrespective of color. The pulp and paper industry accepts, as far as we were able to determine, wood having even a fairly dark color, but does not want wood having a low specific gravity. The box-shook industry apparently discriminates against the dark wood in scaling, even tho it may appear to be still quite hard and firm. If a match industry utilizing aspen wood is ever developed in Minnesota, it is not unlikely that even slight discolorations might be considered as cull. However, the practice of culling varies greatly even in the same industry. The above statements indicate the apparent trend of culling in the various industries utilizing aspen.

In order to determine the cull based on different stages of decay, the following data were obtained from each sample tree:

Diameter of total rot at stump to nearest 1/10 inch

Diameter of total rot at sections 1, 2, 3, 4, etc., to nearest 1/10 inch

Diameter of final and intermediate rot at stump to nearest 1/10 inch

Diameter of final and intermediate rot at sections 1, 2, 3, 4, etc., to nearest 1/10 inch

Diameter of final rot at stump to nearest 1/10 inch

Diameter of final rot at sections 1, 2, 3, 4, etc., to nearest 1/10 inch

In all cases the diameter recorded is the average of two diameters taken at right angles to each other, one being the maximum diameter of the decayed core. In cases where a certain stage of rot was evident at one end of an 8-foot section but not at the other end, the 8-foot section was again cut at the center and the rot measurements were also taken at this point. When a certain stage of rot was evident at one end of such a 4-foot section but not on the other end, it was arbitrarily assumed that the rot extended half way through the 4-foot section. In these cases the volume of decay was figured as a cylinder having a uniform diameter equal to that shown on the exposed face.

As aspen usually reproduces by suckers instead of by seeds, it seemed possible that the common avenue of infection might be through the parent root. To determine the possibility of this type of infection, the roots of a considerable number of dominant trees were dug and the limits of decay determined.

METHOD OF COMPILATION

All volumes were computed inside the bark in cubic feet. The stump was considered as a cylinder with a diameter of the stump cut. All stumps were cut one foot high. The volume of each section was determined by means of Smalian's formula.[8] The volume of the tops was considered as a cone. Both total and merchantable volumes were computed. The merchantable volume was determined from the stump to a 3-inch top diameter inside the bark. The volume of each stage of rot was also determined by the use of Smalian's formula.

It was apparent that decay had so decreased the actual sound wood content of many logs and trees that in actual practice the entire log or tree would have been culled. This study, however, concerns itself only with net or actual cull. As the degree of utilization of practically all forest trees is rapidly changing, there seems to be little advantage in estimating or trying to estimate gross cull.

If a very large number of measurements had been made, the raw averages of the different stages of rot and tree volume would have approached a fairly smooth, continuous curve. The cost of collecting and computing such a large number would be prohibitive. To approximate the results of such a large sample with the least expenditure of time and money, graphic methods were used, which iron out chance fluctuations of the data due to the size of the sample and errors of observation and also permit interpolation to uniform intervals of the independent variable and therefore facilitate comparisons and interpretations.

The volume of total rot, final plus intermediate rot, final rot, peeled total, and merchantable volume were computed for each tree. The trees were then grouped in 10-year age classes (11-20, 21-30) and each of the above items was averaged. The volumes of incipient and intermediate rot were obtained from the averages for each age class by deducting the volume of the intermediate and final rot from the total volume of rot. Each stage of rot was expressed as a percentage of the total rot and also as a percentage of the tree volume.

In order to eliminate widely discordant values, affecting materially the averages, the following procedure was used: A preliminary volume on age curve was drawn among the raw averages so that the sum of the deviations above the curve were approximately equal to those below and so the sum of the raw data and the sum of the values read from the curves checked within 1.5 per cent. An attempt to keep the sum of

[8] Volume in cubic feet $= \left(\frac{b_1+b_2}{2}\right)L$, where b_1 and b_2 are the end areas in square feet and L the length of the section in feet.

the deviations[9] of the actual tree volumes from the curve as small as possible was also made by drawing the curve nearest to the points of greatest weights.

The volume in cubic feet corresponding to the actual age of each tree was read from this curve and the percentage of deviation from the curved value was computed. These deviations in the form of a frequency curve are shown in Figure 1.

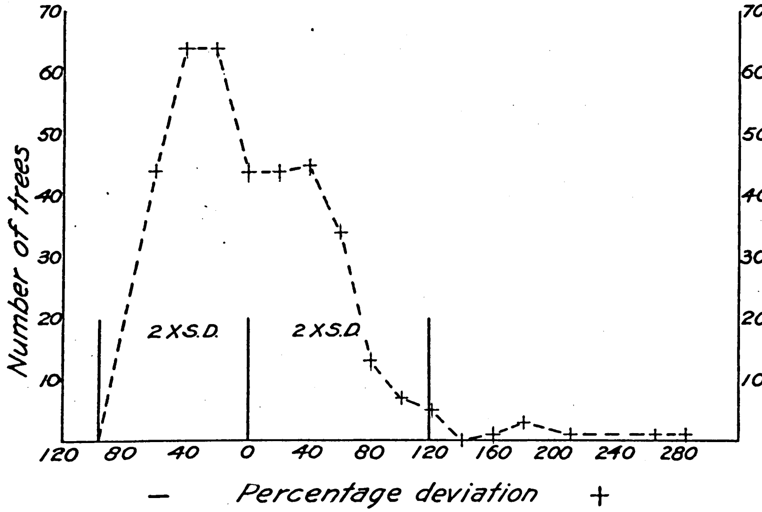

Fig. 1. Frequency Distribution of Percentage Deviations from the Total Peeled Volume Curve Rejection limits equal to twice the standard deviation (S.D.)

The average deviation above and below the curve was computed and found to be +47 per cent and —38 per cent. This wide range is due chiefly to the variation of growing conditions or site represented by the sample. These percentages and the curve of deviations show a positive skewness and for this reason the limit of rejection is greater for the values above the curve than for those below. The factor 1.253, of the normal curve of error, was used for computing the standard deviation from the average deviation. The standard deviation above the curve is 47 per cent × 1.253, or 59 per cent; and below, 38 per cent × 1.253, or 48 per cent. Twice the standard deviation, or +118 per cent and —96 per cent, was arbitrarily taken as the limit of rejection. On this basis, the nine trees noted in Table I were eligible for rejection, but were thoroly examined for mistakes in computing the original data or other causes that might be the reason for the wide deviation before they were finally discarded.

[9] Theoretically, according to the theory of least squares, as the name implies, the sum of the deviations squared should be a minimum.

TABLE I

REJECTED TREES HAVING A PERCENTAGE DEVIATION OF OVER TWICE THE STANDARD DEVIATION

Age, years	Deviation percentage	No. of trees
29	+268	1
30	+287	1
32	+150	1
35	+125	1
37	+174	1
41	+219	1
44	+124	1
50	+172	1
51	+188	1

It is quite evident from the deviation percentages and the frequency curve that these rejections are entirely justified. It is especially necessary to eliminate these trees, as there are no compensating values of opposite sign.

It probably would have been desirable to use total rot as an additional basis for rejection. This would have eliminated a few trees for which the total rot varied considerably from the curve.

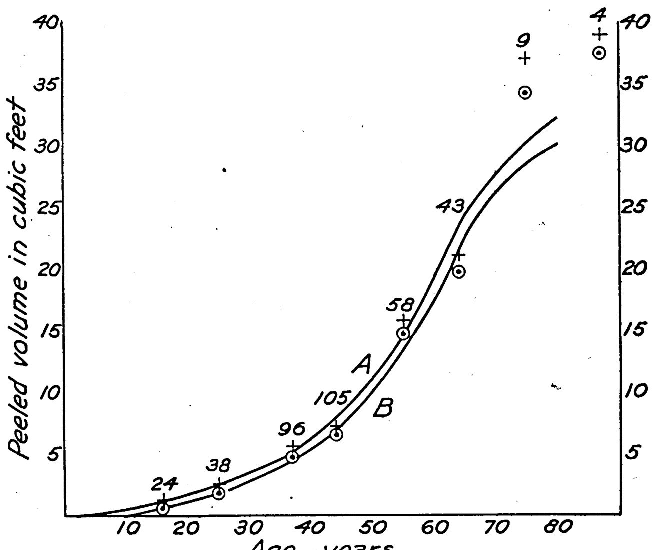

Fig. 2. Peeled Volume in Cubic Feet of Average Tree by Age Classes

A. Total volume including stump, stem, and top

B. Merchantable volume above a 1-foot stump to a top diameter inside of bark of 3 inches

The actual average volumes in cubic feet for each stage of rot—intermediate, final, and total—and peeled volume of trees, and also the percentage of total rot and tree volume, were plotted on age to determine which values showed the most consistent and well defined curves. Examination of these plotted raw averages (similar to Figs. 2, 3, 4, and 5) showed that the actual volumes in cubic feet for the greater portion of the curve and the percentages of the volume showed the least tendency to deviate from a smooth curve. For this reason the actual volumes in cubic feet and the percentages of tree volume were used to obtain the first approximation of the final values. Smooth curves were drawn independently of each other through the raw averages for peeled tree volume, total rot, each stage of rot, and also the latter as percentages of tree volume, and balanced to make the sum of the deviations above the curve approximately equal to the sum of those below. The values

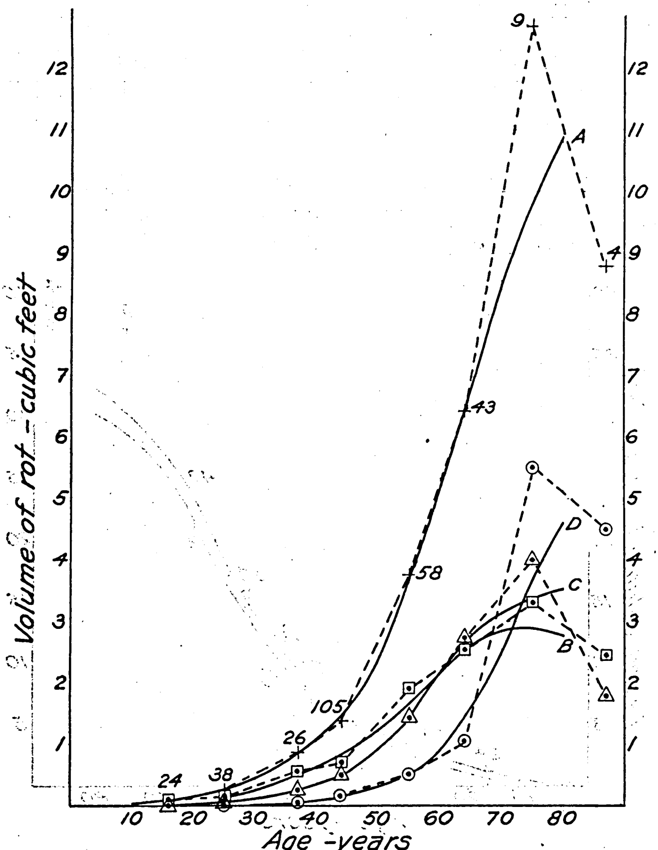

Fig. 3. Volume of Rot in Cubic Feet in Entire Stem of Aspen Trees
A Total rot C Intermediate
B Incipient D Final

for even 10-year periods were read from these curves and a computed value of total peeled tree volume was obtained by dividing the curved volume of rot in cubic feet by the corresponding curved values of rot as a percentage of tree volume. This was done for each stage of rot, including the sum of intermediate and final rot and the total rot. It was also necessary to make the sum of the curved values for the different stages of rot equal the curved total rot. Each series of computed tree volumes was plotted among the original averages to check both trend and balance of the curve. If they did not check, the percentage and cubic volume curves were adjusted until all the curves conformed to the raw averages, cross-checked, and balanced. Any inconsistency in trend in any one curve, especially where the data were scant, showed up in this method of cross-checking. This procedure resulted in five series of computed values for the total peeled volume of the tree and one series of values obtained by curving the raw data in cubic feet. These figures were then averaged by 10-year age classes to obtain the

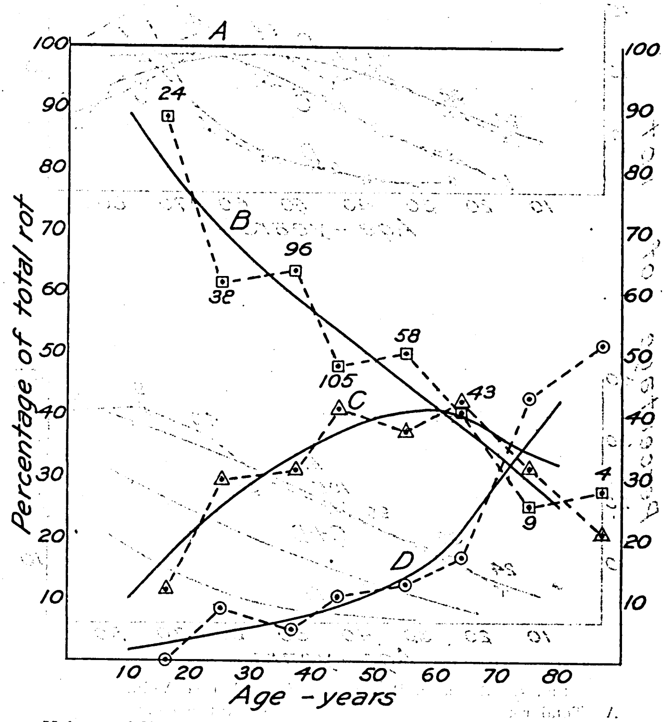

Fig. 4. Volume of Each Stage of Rot as a Percentage of Total Rot in Entire Stem
A Total rot
B Incipient rot
C Intermediate rot
D Final rot

second approximate curve for total tree volume. Additional cross-checks on the trend were made by substituting each factor in terms of each other in the above relation to compute tree volume. After a little adjusting, a position for each curve was found, to alter which, would mean radically changing other values. Such a condition probably represents the most probable value of the variables for a given sample obtained through free-hand curving.

In the above check very little attention or none was paid to each stage of rot as a percentage of total rot. The percentages computed from the cubic foot values obtained above should follow the trend of these averages and also balance among them. The percentages computed from the curved values obtained by the above procedure were used as first approximations in this series of curves; and the same procedure, discussed above, was employed in cross-checking. In this case, the total rot was computed from each stage of rot in cubic feet and the corresponding percentage of total rot, and then averaged to obtain the final total rot. In adjusting these curves, a slight departure from the trend of the raw averages was made in the percentage curve of in-

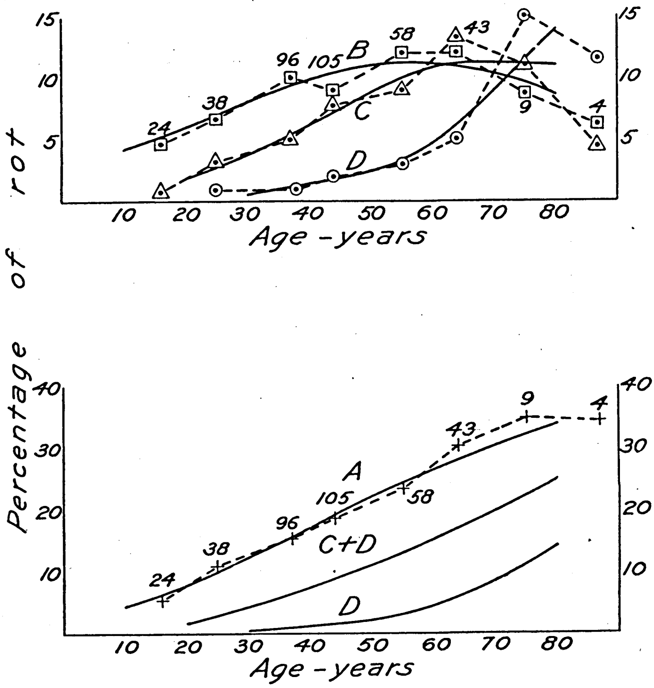

Fig. 5. Rot as a Percentage of Total Tree Volume
A Total rot
B Incipient
C Intermediate
D Final
C+D Intermediate and Final

cipient rot between 50 and 70 years. To follow the original data between these ages, it would be necessary to have the curve of incipient rot as a percentage of total increase and then decrease. This deviation was considered a matter of chance and was therefore partially ironed out, but not without throwing some of the other curves slightly out of balance and trend. The whole system was given a final cross-check, which resulted in further slight readjustments, resulting in the final curves presented in these figures.

The merchantable values were then expressed as a percentage of the corresponding total figures and curved. The curved values for the entire stem were multiplied by these curved percentages to obtain the final merchantable data. As these percentages formed well defined curves, no difficulty was experienced in adjusting them. Rough checks indicate that they conform to the original data as well as to the final figures on total volume.

Any secondary data, especially when compiled by freehand graphic methods, should be checked against the original values. In the theory of least squares these checks are inherent in the method. The arithmetical mean of the curved data for the entire sample should be equal to the mean of the original sample, or, in other words, the sum of the original data should be equal to the sum of the curved values read for each individual observation. Table II gives a comparison of the totals and averages of the original and curved data, and the percentage of error based on the curved values. The curves could be still further adjusted by these small percentages to make the errors negligible.

TABLE II
AGGREGATE CHECK OF RAW AND CURVED DATA

Item	Total volume		Percentage error	Mean	
	Original data	Curved data		Original data	Curved data
	cu. ft.	cu. ft.		cu. ft.	cu. ft.
Total peeled volume	3947	3992	1.2	10.25	10.37
Total rot in entire stem	973	985	1.1	2.53	2.56
Incipient rot	398	399	0.3	1.34	1.36
Intermediate rot	368	366	0.6	0.96	0.95
Final rot	211	212	0.5	0.55	0.55

For the same sample of data, that method of compilation, according to the theory of least squares, gives the best representative values which makes the sum of the deviations squared the least possible. Where freehand methods of curving are used, Bruce[10] has recommended that the sum of the deviations be used instead, because of the amount of work involved in computing the squares. If the sum of the deviations is as small as possible, the average deviation will be also. In this study the average deviations were computed only for total tree volume and total volume of rot, in cubic feet, and are as follows:

Total volume of tree ± 42 per cent (before rejection)
Total volume of rot ± 54 per cent (after rejection)

These values are given in order that they may be compared with those obtained in similar studies which may be undertaken in the future.

The average deviation also represents the degree of scatter of the individual tree values around the curve and in that way indicates the

[10] Bruce, D. A proposed standardization of the checking of volume tables. Jour. For. 18:544-548. 1920.

confidence that can be placed in a prediction by use of the curve. It is readily seen that, with variations on the average of as much as 50 per cent of the curved value, predictions for individual trees or stands are useless. The curves, however, are not presented here for that purpose, but merely to indicate average conditions.

The variation could have been greatly reduced if separate curves had been prepared for each site. The data available, however, were insufficient for this.

DECAY OF ASPEN IN RELATION TO AGE

The field data obtained from 385 sample trees were computed on the basis of both total and merchantable volume. Total volume includes the stump, bole, and top without bark; and merchantable volume the bole without the bark above a one-foot stump to a top diameter of 3 inches inside of bark. In Table III are found the raw data which show the relation between the volume of rot and the age of the stand, based on both the total and the merchantable volume of the tree.

In order to smooth off the results, the data shown in Table III were plotted and curves drawn by employing the methods previously described. In Figure 2 the average peeled total and merchantable volume in cubic feet are plotted on age.

The volume of total rot for the various age classes was obtained from Curve A, Figure 3. The volume of each stage of rot as a percentage of total rot was read from the curves in Figure 4. These percentages were then applied to the volume of total rot resulting in the values presented in Table IV. These values are plotted in Figure 3, Curves B, C, and D.

The percentages given in Table V and plotted in Figure 5 were obtained by dividing the curved rot volumes in cubic feet by the curved tree volumes in cubic feet.

TABLE III
Rot Stages in Aspen by Age Classes
Minnesota
(Basic data)

Age class	Age	Average		Stage of rot												Basis
		Peeled vol. of tree		Intermediate and final				Final				Total				
				Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		
		Total*	Merchant-able†	Vol. of rot	% of total vol.	Vol. of rot	% of merchant-able vol.	Vol. of rot	% of total vol.	Vol. of rot	% of merchant-able vol.	Vol. of rot	% of total vol.	Vol. of rot	% of merchant-able vol.	
years	years	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		Trees
11- 20	16	1.10	0.50	0.01	0.9	...	...	...	...	...	...	0.06	5.5	0.05	10.0	24
21- 30	25	2.39	1.70	0.10	4.2	0.08	4.7	0.02	0.8	0.02	1.2	0.27	11.3	0.24	14.1	38
31- 40	37	5.59	4.82	0.32	5.7	0.28	5.8	0.05	0.9	0.04	0.8	0.88	15.7	0.84	17.4	96
41- 50	44	7.31	6.52	0.72	9.9	0.68	10.4	0.15	2.0	0.14	2.1	1.38	18.9	1.34	20.5	105
51- 60	55	15.84	14.84	1.88	11.9	1.78	12.0	0.47	3.0	0.44	2.9	3.78	23.8	3.64	24.5	58
61- 70	64	21.10	19.61	3.83	18.2	3.62	18.5	1.08	5.1	0.99	5.0	6.41	30.4	6.15	31.4	43
71- 80	75	36.63	34.22	9.54	26.0	9.03	26.4	5.49	15.0	5.24	15.3	12.77	34.8	8.33	35.7	9
81- 90	87	39.03	37.37	6.36	16.3	5.93	15.9	4.54	11.6	4.21	11.3	8.80	22.5	3.88	22.3	9
91-100	97	23.51	22.09	10.67	45.4	10.34	46.8	5.08	21.6	4.94	22.4	10.81	46.0	10.48	47.4	4
101-110	103	29.82	27.40	10.63	35.6	10.33	37.7	7.16	24.0	7.06	25.8	11.14	37.3	10.86	39.6	4
Total																385

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes volume of peeled stem above a 1-foot stump to a top diameter of 3 inches inside of bark.

TABLE IV

Volume of Rot in Aspen Trees

Minnesota

Age	Stage of rot																			
	Incipient				Intermediate				Final				Intermediate and final				Total			
	Total vol.*		Merchantable vol.†		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.	
	Vol. of rot	% of total rot	Vol. of rot	% of merchantable rot	Vol. of rot	% of total rot	Vol. of rot	% of merchantable rot	Vol. of rot	% of total rot	Vol. of rot	% of merchantable rot	Vol. of rot	% of total rot	Vol. of rot	% of merchantable rot	Vol. of rot	% of total tree vol.	Vol. of rot	% of merchantable vol.
Yr.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
10	0.02	88.8	...	...	...	10.1	...	...	...	...	...	...	...	...	...	...	0.02	4.4	...	...
20	0.10	75.5	0.09	81.8	0.03	20.9	0.02	18.2	...	3.6	...	...	0.03	24.5	0.02	18.2	0.13	8.1	0.11	11.5
30	0.28	65.5	0.27	67.5	0.13	29.1	0.11	27.5	0.02	5.4	0.02	5.0	0.15	34.5	0.13	32.5	0.43	12.5	0.40	14.8
40	0.61	56.7	0.60	58.8	0.38	35.5	0.35	34.3	0.08	7.8	0.07	6.9	0.46	43.3	0.42	41.2	1.07	17.4	1.02	18.9
50	1.20	49.3	1.18	50.4	0.97	39.6	0.92	39.3	0.27	11.1	0.24	10.3	1.24	50.7	1.16	49.6	2.44	22.1	2.34	23.0
60	2.18	41.8	2.14	42.8	2.13	41.0	2.03	40.6	0.90	17.2	0.83	16.6	3.03	58.2	2.86	57.2	5.21	26.8	5.00	27.5
70	2.85	33.6	2.80	34.4	3.13	36.8	2.98	36.5	2.51	29.6	2.37	29.1	5.64	66.4	5.35	65.6	8.49	30.4	8.15	31.2
80	2.78	25.6	2.74	26.2	3.51	32.2	3.34	32.0	4.59	42.2	4.36	41.8	8.10	74.4	7.70	73.8	10.88	33.8	10.44	34.6

* Total volume includes stump, stem, and top without bark. The values of rot under total volume were compiled by multiplying the total rot figures by the curved percentages for each stage of rot.

† Merchantable volume includes peeled volume of stem above a 1-foot stump to a top diameter of 3 inches inside bark.

TABLE V
ROT AS A PERCENTAGE OF TREE VOLUME OF ASPEN
Minnesota

Age	Stage of rot										Peeled volume of tree	
	Incipient		Intermediate		Final		Intermediate and final		Total rot			
	Total*	Merchantable†	Total	Merchantable	Total	Merchantable	Total	Merchantable	Total	Merchantable	Total	Merchantable
Yr.	%	%	%	%	%	%	%	%	%	%	cu. ft.	cu. ft.
10	4.4	...	...	...	...	...	...	...	4.4	...	0.45	...
20	6.2	9.3	1.9	2.1	...	...	1.9	2.1	8.1	11.5	1.60	0.97
30	8.1	10.0	3.8	4.1	0.6	0.7	4.4	4.8	12.5	14.8	3.45	2.71
40	9.9	11.1	6.2	6.5	1.3	1.3	7.5	7.8	17.4	18.9	6.15	5.41
50	10.8	11.6	8.8	9.0	2.4	2.4	11.2	11.4	22.1	23.0	11.05	10.18
60	11.2	11.8	11.0	11.1	4.6	4.6	15.6	15.7	26.8	27.5	19.45	18.20
70	10.2	10.7	11.2	11.4	9.0	9.1	20.2	20.5	30.4	31.2	27.90	26.15
80	8.6	9.1	10.9	11.1	14.3	14.4	25.2	25.5	33.8	34.6	32.20	30.19

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes the peeled volume of the stem above a 1-foot stump to a top diameter of 3 inches inside bark.

In Table VI are given the gross and net volume of aspen at different ages. The net volume tables were obtained by deducting the volume of the various stages of rot from the tree volume.

TABLE VI
GROSS AND NET VOLUME OF ASPEN TREES
Minnesota

Age	Peeled volume of tree							
	Gross volume		Net volume (deducting)					
			Final rot		Intermediate and final		Total rot	
	Total*	Merchantable†	Total	Merchantable	Total	Merchantable	Total	Merchantable
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
10	0.45	...	0.45	...	0.45	...	0.43	...
20	1.60	0.97	1.60	0.97	1.57	0.95	1.47	0.86
30	3.45	2.71	3.43	2.69	3.30	2.58	3.02	2.31
40	6.15	5.41	6.07	5.34	5.69	4.99	5.08	4.39
50	11.05	10.18	10.78	9.94	9.81	9.02	8.61	7.84
60	19.45	18.20	18.55	17.37	16.42	15.34	14.24	13.20
70	27.90	26.15	25.39	23.78	22.26	20.80	19.41	18.00
80	32.20	30.15	27.61	25.79	24.10	22.45	21.32	19.71

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes peeled volume of stem above a 1-foot stump to a top diameter of 3 inches inside of bark.

The periodic annual growth and decay were computed from the data presented in Tables IV and VI and the results are shown in Table VII and Figure 6.

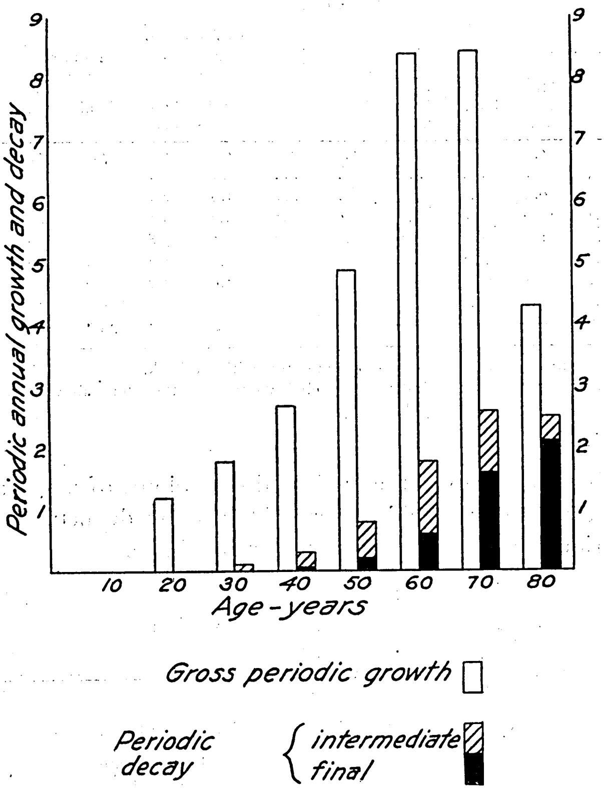

Fig. 6. Gross Periodic Growth and Periodic Decay in Aspen Trees (in tenths of cubic feet)
Based on total volume of stem excluding bark

The basic data upon which this study is based were obtained from individual sample trees. In order to determine the effect of decay on rotation, it is necessary to use the stand as a basis for the computations rather than the individual tree. The stand is the unit of management, the mean annual growth of which culminates long before that of the individual tree. To obtain these stand data, the percentages of rot in the average tree for different age classes were applied to the corresponding yields per acre of well stocked aspen stands on average sites.

The figures for the stand are based on the total yield per acre in cubic feet of all trees one inch in diameter and over, and are taken from unpublished normal yield tables for aspen in Minnesota. The percentages of rot found in the present study were applied directly to these values. This is the sample tree method and for this reason inherits the errors involved in it. The results of these calculations are shown in Table VIII and Figure 7.

TABLE VII
Periodic Annual Growth and Decay in Aspen Trees
Minnesota

Age	Periodic annual growth								Periodic annual decay											
	Gross		Net (deducting)						Final rot				Intermediate and final rot				Total rot			
			Final rot		Intermediate and final		Total rot		Total		Merchantable		Total		Merchantable		Total		Merchantable	
	Total*	Merchantable†	Total	Merchantable	Total	Merchantable	Total	Merchantable	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
10	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
20	0.12	...	0.12	...	0.11	...	0.11	...	...	...	...	...	...	...	...	...	0.01	8.3	...	...
30	.18	0.17	.18	0.17	.17	0.16	.15	0.14	...	...	...	...	0.01	5.6	0.01	5.6	.03	16.7	0.03	16.7
40	.27	.27	.26	.26	.24	.24	.21	.21	0.006	2.2	0.005	1.9	.03	11.1	.03	11.1	.06	22.2	.06	22.2
50	.49	.48	.47	.46	.41	.41	.35	.35	.02	4.1	.02	4.2	.08	16.3	.07	14.3	.14	28.6	.13	26.5
60	.840	.802	.78	.74	.66	.63	.56	.53	.06	7.1	.06	7.5	.18	21.6	.17	21.2	.28	33.3	.27	33.7
70	.845	.80	.68	.65	.58	.55	.52	.48	.16	18.9	.15	18.7	.26	30.8	.25	31.2	.33	39.1	.32	40.0
80	0.43	0.40	0.22	0.20	0.18	0.16	0.19	0.17	0.21	48.8	0.20	50.0	0.25	58.1	0.24	60.0	0.24	55.8	0.23	57.5

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes the peeled volume of the stem above a 1-foot stump to a top diameter of 3 inches inside of bark.

Double lines show culmination of periodic annual growth.

TABLE VIII
GROSS AND NET YIELD AND VOLUME OF ROT PER ACRE
WELL-STOCKED ASPEN STANDS ON AVERAGE SITES
Minnesota

	Total yield per acre*								
		Net (deducting)			Volume of rot per acre				
Age	Gross†	Final rot	Intermediate and final rot	Total rot	Incipient	Intermediate	Final	Intermediate and final	Total
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
20	1150	1150	1130	1060	70	20	...	20	90
30	1760	1750	1680	1540	140	70	10	80	220
40	2500	2470	2310	2060	250	160	30	190	440
50	3220	3140	2860	2510	350	280	80	360	710
60	3820	3640	3220	2800	420	420	180	600	1020
70	4290	3900	3420	2990	430	480	390	870	1300
80	4600	3940	3450	3050	400	490	660	1150	1550

* Total yield includes stump, stem, and top without bark of all trees one inch in d.b.h. and over.

† Gross yield figures are values of the 60-foot site index class from the normal yield tables for aspen compiled in 1926 by S. Gevorkiantz.

That these percentages can be applied to an average tree differing in volume from that shown in this study, is indicated by the data presented in Table IX, which show that the percentage of rot for each age class does not vary greatly for trees of different size. The two high values in the table for suppressed trees are based on one tree only and can not, therefore, be considered significant.

TABLE IX
ROT AS A PERCENTAGE OF TOTAL TREE VOLUME BY CROWN CLASSES
(Raw data)

Age	Crown class		
	Dominant	Intermediate	Suppressed
yr.	per cent	per cent	per cent
11-20	6	..	..
21-30	11	11	12
31-40	16	18	17
41-50	19	24	17
51-60	24	24	43*
61-70	30	27	36*
71-80	35	..	..

* One tree only.

These results do not agree with the idea held by some, that rapidly growing thrifty trees resist, or at least limit, the attacks of wood-destroying fungi. Furthermore, they are not in accord with the results of Eklund and Wennmark[11] in their study of *Populus tremula* in Sweden. They claim that vigorous stands are more resistant to stem rot than less vigorous stands. They found, in stands of the same age, that the percentage of total rot decreases rapidly as the growth percentage (after Pressler) increases.

[11] Eklund, S. and Wennmark, G. loc. cit.

Whether or not there is any great variation in the percentage decay in different sized trees of the same age is a very important question and merits a more comprehensive study. If the variation is small, as found in this study, the pathological problem in even aged stands on different sites is greatly simplified and it will be possible to apply pathological data to yield figures for all sites upon which the particular tree species is found in well stocked stands. If, however, further study does not

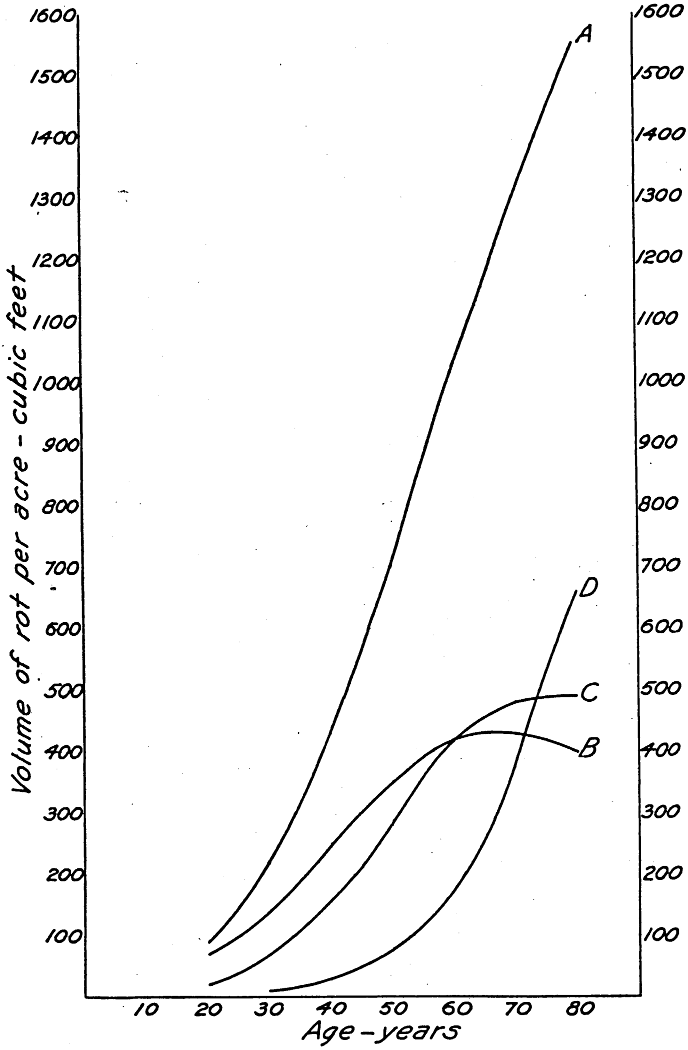

Fig. 7. Volume of Rot per Acre in Well Stocked Aspen Stands on Average Sites
Based on the total yield pe: acre in cubic feet excluding bark
A Total rot
B Incipient
C Intermediate
D Final

confirm the results here reported, it will be necessary to gather pathological data representative of the different sites.

In Table X are shown the gross and the mean annual growth and decay per acre for well stocked aspen stands on average sites.

The gross mean annual growth and mean annual decay per acre in well stocked aspen stands on average sites are shown in Figure 8.

Curves showing the culmination of gross and net mean annual growth per acre in well stocked stands on average sites are shown in Figure 9.

Gross and net periodic annual growth and decay are shown in Table XI. In Figure 10 are shown the gross periodic annual growth and periodic annual decay per acre in well stocked stands on average sites.

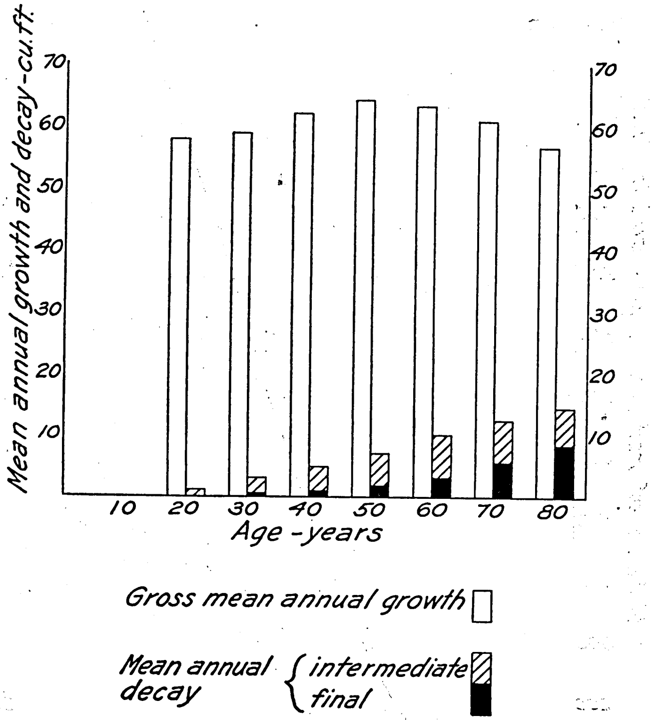

Fig. 8. Gross Mean Annual Growth and Mean Annual Decay per Acre in Well Stocked Aspen Stands on Average Sites
Based on total yield per acre excluding bark

Since incipient decay is ordinarily omitted in figuring cull in aspen for most uses, it is omitted from most of the following discussion. Age classes above 70 years are also omitted, as there is little likelihood that aspen will be grown on rotation over 70 years.

TABLE X

GROSS AND NET MEAN ANNUAL GROWTH AND DECAY PER ACRE. WELL STOCKED ASPEN STANDS ON AVERAGE SITES*
Minnesota

Age	Mean annual growth per acre				Mean annual decay per acre									
	Gross	Net (deducting)			Incipient		Intermediate		Final		Intermediate and final		Total rot	
		Final	Intermediate and final	Total rot	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
20	58	58	56	53	3.5	6.0	1.0	1.7	...	...	1.0	1.7	4.5	7.7
30	59	58	56	51	4.7	8.0	2.3	3.9	0.3	0.5	2.6	4.4	7.3	12.4
40	62	62	58	51	6.2	10.0	4.0	6.4	0.8	1.3	4.8	7.7	11.0	17.7
50	64.4	63	57	50	7.0	10.8	5.6	8.7	1.6	2.5	7.2	11.2	14.2	22.0
60	63.7	61	54	47	7.0	11.0	7.0	11.0	3.0	4.7	10.0	15.7	17.0	26.7
70	61	56	49	43	6.1	10.0	6.9	11.3	5.6	9.2	12.5	20.5	18.6	30.5
80	57	49	43	38	5.0	8.8	6.1	10.7	8.3	14.6	14.4	25.3	19.4	34.1

* Based on a yield including the stump, stem, and top without bark of all trees 1 inch d.b.h. and up.
Double lines show culmination of periodic annual growth.

TABLE XI

Gross and Net Periodic Annual Growth and Decay. Well Stocked Aspen Stands on Average Sites
Minnesota

Age	Periodic annual growth per acre*				Periodic annual decay per acre									
	Gross	Net (deducting)			Incipient		Intermediate		Final		Intermediate and final		Total rot	
		Final	Intermediate and final	Total rot	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
20	..	..	..	..	..	...	..	...	..	...	..	...	..	...
30	61	60	55	48	7	11.5	5	8.2	1	1.6	6	9.8	13	21.3
40	74	72	63	52	11	14.9	9	12.2	2	2.7	11	14.9	22	29.8
50	72	67	55	45	10	13.9	12	16.7	5	6.9	17	23.6	27	37.5
60	60	50	36	29	7	11.7	14	23.3	10	16.7	24	40.0	31	51.7
70	47	26	20	19	1	2.1	6	12.8	21	44.7	27	57.5	28	59.6
80	31	4	3	6	3†	9.7†	1	3.2	27	87.1	28	90.3	25	80.6

* Based on a ten-year period and on a yield including the stump, stem, and top without bark of all trees one inch in d.b.h. and over.

† Decrease.

Double lines show culmination of periodic annual growth.

At 70 years, 20.2 per cent of the total volume of the tree is in intermediate and final stages of rot; at 60 years, 15.6 per cent; at 50 years, 11.2 per cent, and at 40 years, 7.5 per cent. If the intermediate stage of decay is disregarded and only the final stage of rot is culled, then at 70 years the total volume of the tree is reduced 9.0 per cent; at 60 years, 4.6 per cent; at 50 years, 2.4 per cent, and at 40 years, 1.3 per cent.

On the basis of merchantable volume, the values are quite similar. For example, at 70 years the final rot and intermediate stage of decay account for 20.5 per cent of the merchantable volume; at 60 years, 15.7 per cent; at 50 years, 11.4 per cent; and at 40 years, 7.8 per cent. If only the final stage of decay is considered, it is evident that the merchantable volume is reduced 9.1 per cent at 70 years, 4.6 per cent at 60 years, 2.4 per cent at 50 years, and 1.3 per cent at 40 years.

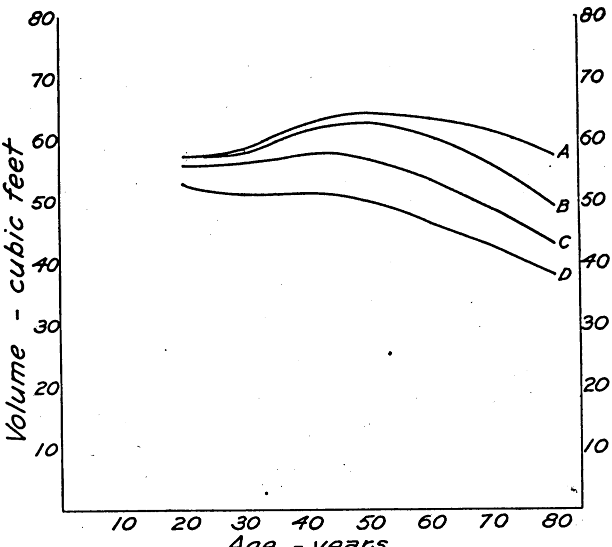

Fig. 9. Culmination of Gross and Net Mean Annual Growth per Acre in Well-Stocked Aspen Stands on Average Sites

A Gross mean annual growth
B Net growth, deducting final rot
C Net growth, deducting final and intermediate rot
D Net growth, deducting total rot

These deductions for defects due to decay in aspen will largely depend on the specific use to which the wood is put. A superficial study of the wood requirements of the excelsior industry indicates that small amounts of decay, even of the final stage, do not seriously interfere with the use of aspen for excelsior. Portions of billets showing advanced stages of decay are not actually used, but the comparatively sound wood immediately surrounding the rot apparently is used.

In the box shook industry, brown heartwood, if firm, is ordinarily not considered a serious defect. It must be very difficult, however, to determine when brown heartwood is sound enough for use, as even when apparently firm the annual rings very often separate and the wood checks badly in drying.

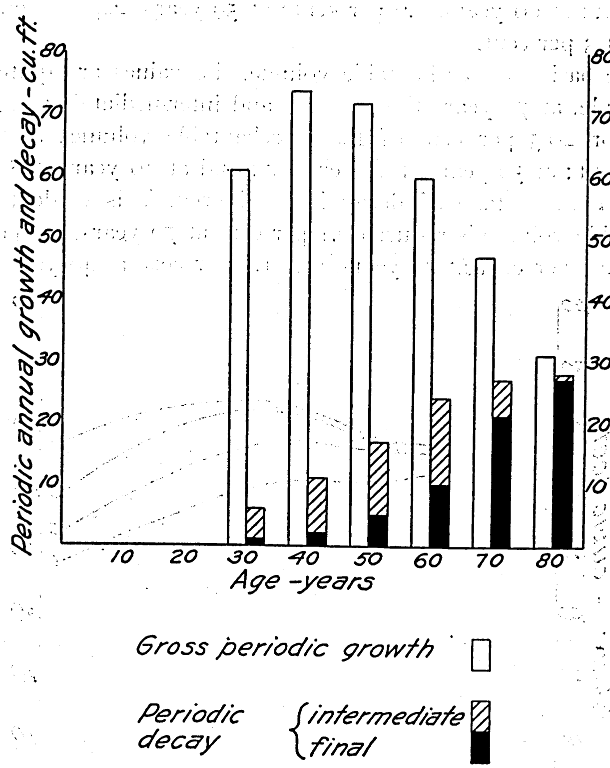

Fig. 10. Gross Periodic Annual Growth and Periodic Annual Decay per Acre in Well-Stocked Aspen Stands on Average Sites. Based on total yield per acre excluding bark

For some boxes a light colored wood has certain advantages, in which case almost any marked coloration is objectionable. From the point of view of this study, final rot should certainly be culled in the box shook industry and the intermediate stage of decay may or may not be considered a defect, depending upon the use to which the box is put.

In the pulp industry, yield of cellulose, color of pulp, and strength of sheet are important considerations. Apparently the pulp industry has not yet determined the exact stage in the deterioration of aspen at which it is no longer profitable or desirable for use, but it is obvious that wood showing even advanced stages of decay is sometimes used. This phase offers interesting problems for further study.

In the use of aspen for rough construction lumber, a slightly darkened color should not be a serious drawback if the mechanical properties of the wood are not seriously affected by the rot. Such wood should not be used in exposed places or in contact with the soil.

The curves showing the different stages of rot as percentages of total rot show that in young trees incipient decay forms a large percentage of the total rot. This percentage, however, decreases rapidly with an increase in age. The intermediate stage of rot is negligible when the trees are very young, but the percentage increases rapidly up to about 60 years and then decreases. The final stage of rot is not evident until the trees reach an age of approximately 30 years, but thereafter it rapidly increases.

A tract of timber managed for the perpetual production of forest products should be so handled that each and every unit or stand is producing at maximum efficiency. In order to obtain the maximum growth for a particular site and a particular species, it is necessary, in addition to proper silvicultural treatment during the life of the stand, to harvest it during the age interval in which the peak of production of a given product occurs. When such mass products are grown as excelsior wood, pulpwood, etc., in which size is not the limiting consideration, the age interval during which the mean annual growth of sound wood culminates makes the most efficient stand. The stand, however, and not the individual tree must be taken as the producing unit, because the average tree continues to grow long after the stand begins to decline, and for this reason its growth culminates later than that of the stand. Our data show that in Minnesota in well stocked aspen stands on average sites, the gross mean annual growth culminates at about 50 years, and when the volume of final and intermediate rot is deducted the growth culminates nearer to 40 years. This seems to indicate, under extensive management, a modified economic rotation of from 40 to 50 years for the production of mass products. When the final rot only is deducted, the mean annual growth culminates at about 50 years.

DECAY OF ASPEN IN RELATION TO INJURIES

Heartrot in aspen in northern Minnesota is so prevalent and widespread that it is the very exceptional tree above 20 years of age that does not show some discoloration of the wood.

From a theoretical point of view, every branch scar is a possible source of infection. It is, however, in most cases impossible to determine the exact mode of entry of the fungus. This is particularly true when the more advanced stages of decay are concerned and when almost every open branch scar is producing a fruiting body of *Fomes igniarius*.

On the older trees from fifteen to twenty fruiting bodies of this fungus on a single tree are not at all uncommon.

Our field observations seemed to show conclusively that fire scars are very important avenues of entrance of *Fomes igniarius*. Seldom was a tree found having a fire scar even a few years old that did not show the final stage of decay. Often very high percentages of cull, especially in the butt log, were associated with fire scars near the ground line. Whether or not these scars were the only or the first means of entry of the fungus could not be determined, but in most cases it seemed probable that they were only accessory means of infection. Large scars permit a considerable volume of sapwood, ordinarily not attacked by heartrot, to dry out partially and decay. It is possible that large fire scars influence the moisture content of the wood for some distance from the scar and at the same time allow freer entry of air, thus making conditions more favorable to rapid decay. Better fire protection will undoubtedly materially reduce the losses from decay in aspen stands.

Insect injuries are also important avenues of entrance of wood-destroying fungi in aspen. Two of the most important and prevalent insects affecting aspen in Minnesota are the aspen borer, *Saperda calcarata* Say., and the carpenter moth, *Prionoxystus rodiniae* Peck. In certain regions both insects seem to be more common than in others. In the vicinity of Itasca Park, deformed trees with dead tops are numerous and have from one to several large scars from which a brownish liquid and frass exudes. The wood beneath these scars is riddled by the larvae and more or less completely decayed by wood-destroying fungi. These decayed areas, especially when near the tops of trees, are often limited both above and below by sound wood, indicating that the fungus entered through the surface scar or the larval mines.

It is not unusual in recent infestations to find that the wood around the larval mines is of an intense yellow color and possesses a strong, rather disagreeable odor. The discolored wood seems to be saturated with water and sometimes "bleeds" profusely when cut. Results obtained in culturing this wood indicate that the coloration may not always be due to the activities of wood-destroying fungi. Sooner or later, however, wood-destroying fungi gain access through these injuries and decay proceeds.

Ants often take possession of these old larval mines and further destroy the wood. Numerous cases were found where the entire center of the tree for a longitudinal distance of five or six feet was almost entirely destroyed, leaving nothing but a thin shell of wood. Above this point the top generally dies and is eventually broken off.

On the Cloquet Forest Experiment Station, a large number of small trees 16 to 18 years old were found to be infested with a borer, probably

Plectrodera scalator Fabr. The borer was always found near the ground line and at times the larval mines extended some distance below the ground line into the roots. The larvae of the flat-headed borer, *Poecilonota cyanipes* Say., were often found in trees infested with the aspen borer. In general, however, the flat-headed borer seems not to cause as much damage as the aspen borer, in Minnesota.

Hofer[12] recommends either the cutting of the brood trees or the painting of the scars with carbolineum as a measure to control the aspen borer. Such steps would not, under present economic conditions, be feasible in Minnesota. Hofer also points out that in Utah trees on dry, rocky slopes appear to be more subject to attack than those on less exposed situations. Along the low, moist creek beds and mountain meadows the attack was not so severe as on the drier slopes. It may well be that the attacks of the aspen borer will be materially reduced in Minnesota when silvicultural methods which tend to maintain a maximum rate of growth are applied to the stands.

ROOT STUDIES

As aspen reproduces largely by means of suckers, the possibility of infection through the mother root needs consideration. After an aspen tree has been cut, the stump decays very rapidly and as heartrot which extends into the stump is prevalent in all the comparatively older age classes, the possibility of spread of heartrot from the decayed stump through the roots to an offspring tree presents an important problem.

In coppice the situation is quite different. Here sprouts may become infected directly from the parent stump, as has been shown by Mattoon[13] and others.[14] In chestnut, Mattoon observed that "the infection mainly due to fungi of various sorts spreads from the parent stump upward and was observed to be most in evidence at the base of the shoot." In the case of suckers, the parent and the offspring trees may be separated by many feet of root system. Aspen may also sprout from the stump, but that this method of reproduction is comparatively unimportant is indicated by the work of Baker,[15] who found that of 6724 sprouts 91 per cent were root suckers, 8 per cent were from the root collar, and 1 per cent from the stump. Baker also found that certain small roots appear to be devoted primarily to reproduction, as they run

[12] Hofer, G. The aspen borer and how to control it. U. S. Dept. Agr. Farmers' Bull. 1154. 1920.

[13] Mattoon, W. R. The origin and early development of chestnut sprouts. Forestry Quarterly 7:34-44. 1909.

[14] Long, W. H. The death of chestnuts and oaks due to *Armillaria mellea*. U. S. Dept. Agr. Bur. Plant Indust. Bull. 89, 1914. Zon, Raphael. Chestnut in Southern Maryland. Bur. Forestry Bull. 53. 1904.

[15] Baker, F. S. Aspen in the Central Rocky Mountain Region. U. S. Dept Agr. Bull. 1291. 1925.

for long distances in the shallower soil layer without much change in diameter or furcation and with practically no feeding rootlets. As a rule, also, the sprouting usually takes place a considerable distance from the stump. Sprouts are frequently found near aspen stumps, but these usually come from roots of distant trees, brought near the surface in crossing the large stump roots.

Weigle and Frothingham[16] found that suckers are not produced from roots covered with 6 inches or more of clay and sod, altho they will develop abundantly if the soil is loose and only 2 inches thick. Suckers are produced only by roots which are near the surface and consequently are very liable to injury by animals or logging operations.

Little is found in the literature concerning the possibility of heartrot spreading from the parent stump through the root to the sucker. In this connection it is important to distinguish clearly between typical heartrots and the rootrots that cause a limited amount of heart or butt rot. Since *Armillaria mellea,* one of the more important fungi causing rot in aspen, is an organism of the latter type, it may well be that this fungus and *Fomes igniarius* spread in quite different ways.

Meinecke[17] recognizes the possibility of trees becoming infected through the roots, but no indication is given as to whether these infections result from injuries to the root or spread from the parent stump. From the data presented, however, it is clear that quite irrespective of how the roots became infected, they are of minor importance in connection with the decay of aspen in Utah.

Eklund and Wennmark,[18] in their study of *Populus tremula* in Sweden, studied in considerable detail the question of root infection and that of fungi spreading from a tree to its suckers through the root system. Their observations dealing with the latter point appear somewhat contradictory.

They found root rots were very common on grazed areas and that the roots on such areas always showed numerous injuries. In every case rots appeared in the wounds and usually the rhizomorphs which are characteristic of *Armillaria mellea* were found. They also found that the fungus does not grow further out from the wound in the root branches, but only spreads toward the tree. In no case was any rot found more than 2½ meters from the tree.

As to *Armillaria* rot spreading from the stump to the suckers, Eklund and Wennmark say in part[19] "The opinion is commonly held

[16] Weigle, W. G. and Frothingham, E. H. The aspens: Their growth and management. U. S. Dept. Agr. Forest Serv. Bull. 93. 1911.

[17] Meinecke, E. P. loc. cit.

[18] Eklund, S. and Wennmark, G. loc. cit.

[19] The writers are indebted to Dr. Gunnar Nilsson-Lissner for this translation of Eklund and Wennmark's work.

by foresters that the rot spreads from the stump to the suckers. In order to clear up this question, we blew up a large number of stumps in an area cut over about six years ago, now bearing a dense stand of aspen suckers. The root branches of the old stumps could thus very easily be followed out to the suckers. An inspection of these small trunks showed them to be infected by decay as early as about 6 years of age. The rot followed upward as well as downward in the trunk and seemed to be more prevalent in the stump itself. The old connection between the mother tree and sucker, however, *was completely healthy.*[20] No positive opinion can be expressed as to the nature of this rot as all attempts to cultivate the fungus in a culture have failed. It is impossible that *Fomes igniarius* has already entered through wounds or dry broken branches at this age."

"It is rather interesting to compare these results with the results obtained from Plot 3. In the latter case the trees came from suckers after cutting about 25 years previously. Seventy per cent of the trunks showed heartrot with a diameter of one to three centimeters in the stump cut. These stumps were blasted out and the spreading of the rot and the connections between adjacent trees observed. The fungus had evidently grown from one tree over the other. It was impossible to trace out exactly how the rot got into the trees on this plot. It is not very probable that it entered through wounds on the roots caused by cattle since no injuries worth mentioning could be found. *We, however, consider the best explanation to be that the rot spread from the old stump to the suckers. After a certain number of years the old stump trunk is completely decayed and the root branches also become infected to such an extent that the rot works its way through the connecting root branches and at last reaches the now fairly well developed trees.* This assumption also throws light on the fact that on the five to six year old suckers inspected the young trunks were diseased but the old root branches were healthy." In view of the fact that Eklund and Wennmark found the connection on 5- to 6-year-old suckers and the roots to be perfectly healthy and as no positive evidence was found on Plot 3 that the decay entered the 25-year-old suckers from the roots, the conclusion that the decay entered through the parent root seems hardly warranted. How the interpretation of the facts found on Plot 3 throws any light on the fact that the 5- to 6-year-old suckers were diseased but the old root connection healthy, is not clear.

It is important to note that the above discussion refers to root rot caused by *Armillaria mellea.* Eklund and Wennmark found the case of *Fomes igniarius* quite different. Here, as a rule, the disease seems

[20] The italics in this case are ours.

to be checked in the stump, but in several instances it was found passing out into some of the larger root branches for a distance not exceeding a half meter from the stump, beyond which healthy wood was found to occur.

During the course of the field work in connection with the study of the decay of aspen in Minnesota, more than thirty stumps were dug and the roots carefully examined in order to determine how far the decay extended into the root system. In all but three cases discolorations of any consequence did not extend into the root system for a greater distance than six inches and in by far the greatest number of cases the decay actually terminated in the base of the stump.

In one of the three exceptions mentioned above, the decay in the root was undoubtedly caused by *Armillaria mellea,* as numerous rhizomorphs were found adhering to this root. In this particular case the root had been injured, about 20 years previously, and had not entirely healed. Nevertheless the decayed core in the root was not over an inch in diameter and did not extend outward more than 4 inches beyond the injury.

In the two other exceptions mentioned, the rot extended out 8 to 10 inches from the stump in the large primary roots. Whether or not the decay in these cases was due to *Armillaria mellea* or *Fomes igniarius* could not be determined, but it is believed that it was caused by the latter fungus, as the rot in the bole of these particular trees was undoubtedly caused by *Fomes igniarius.*

Insect galleries extending for a considerable distance into the roots of aspen may be found in both young and older trees. Surrounding these galleries, a dark zone of discolored wood is found which is hard and firm and which when placed in culture did not yield a fungus. The inner surface of these galleries is also very smooth and shiny, further indicating that the discolored zone has probably been caused by the insect rather than by wood-destroying fungi.

A large number of young suckers showed discolorations—even 3- to 5-year-old suckers. In no case, however, could this discoloration be traced down into the parent root. It was always associated with an insect sting, resulting in small swellings near the base of the suckers. The insect causing these swellings and the character of the discoloration produced could be definitely determined. It is possible that this discoloration is indicative of incipient decay, resulting through the tiny branch scars common near the base of the suckers even at this early age. Similar insect stings were also commonly found on the branches near the tops of older trees, where they always caused brown discolorations near the center of the branch. This discolored wood always gave negative results in culture.

In general, then, no evidence was found to indicate that the decay caused by *Fomes igniarius* extends any appreciable distance out in the root system, or that the suckers are infected through the parent root of the old mother stump. This does not mean that infection in this manner may not be possible where *Armillaria mellea* is causing the decay. Since *Armillaria* rot in living trees was not at all common, or could not be recognized as such in Minnesota, our results neither confirm nor contradict the observations made by Eklund and Wennmark regarding *Armillaria mellea* on *Populus tremula* in Sweden.

CULTURE STUDIES

Since there is a great variation in the color of decayed aspen heartwood, it seemed desirable to attempt to determine the causal organism by cultural methods. It is, of course, an open question whether or not the three stages of decay discussed earlier in this paper are merely different stages of decay caused by the same fungus or are caused by different fungi.

The fact that fruiting bodies of *Fomes igniarius* are practically the only ones found on aspen in Minnesota points to *Fomes igniarius* as the probable cause. In only two cases were fruiting bodies of other fungi found on aspen. These were fruiting bodies of *Armillaria mellea* found near the ground line on two large, very defective trees. Both these trees also bore a large number of sporophores of *Fomes igniarius*. In all, 271 field cultures[21] were made. The results of these cultures are presented in Table XII.

TABLE XII
RESULTS OF CULTURES MADE FROM ASPEN WOOD

Stage of decay	Total cultures	Sterile cultures		Bacterial cultures		Fungus cultures	
		No.	Per cent total	No.	Per cent total	No.	Per cent total
Incipient	103	84	81.5	5	4.9	14	13.6
Intermediate	90	50	55.5	18	20.1	22	24.4
Final	49	3	6.1	..*	...	46	93.8
Dark wood of living branches	29	29	100.0	..*	...	..	...

* In two cases bacteria were present in addition to a fungus.

Inoculations from "incipient" stages are usually negative. The final stage of decay usually produces a fungous growth when cultured. These results confirm those obtained by Baxter[22] in his work on heartrot of black ash, that the hyphae of the fungus were always present inside of the black zone. On the other hand, Kauffman and Kraber[23] point

[21] The culture medium employed in this work had the following composition: distilled water 1000 cc., malt extract 25 gm., bacto-agar 15 gm.

[22] Baxter, D. V. The heartrot of black ash. *Polyporus hispidus* Fr. Papers of Mich. Acad. Sci., Arts, and Letters 3:39-50. 1923.

[23] Kauffman, C. H. and Kraber, H. M. A study of the white heartrot of locust caused by *Trametes robiniophila*. Amer. Jour. Bot. 9:493-508. 1922.

out that the mycelium of *Trametes robiniophila* Murr. may be found beyond the rot in apparently sound locust wood. Inside of the black border zone, however, they found no hyphae, but evidence of their former presence was plentiful. In our study of *Fomes igniarius* on aspen, it is apparent that the hyphae do not disappear inside of the black zone, but are present in greatest abundance in that region.

There are at least two possible explanations for the results shown in Table XII. The first is that the discoloration of heartwood is the result of an injury of almost any kind—mechanical or caused by insects, fungi, etc.—but that in only comparatively few cases it is caused by wood-destroying fungi.

The work of Münch[24] supports this explanation. He concludes that the blackened substance in such discolored wood is not the secretion of living cells, but arises only after the death of the cells, as an oxidation product of the cell contents, and that the presence of wood-destroying fungi greatly accelerates the oxidation process.

Another explanation for the large number of negative cultures may be that the discoloration is, as a rule, caused directly by wood-destroying fungi and that either the color reaction extends far beyond the point of infection or the presence of a very small number of hyphae may cause considerable discoloration. The latter explanation seems the more plausible in spite of the fact that cases were observed in which the discoloration was unmistakably the result of insect damage.

The rather common occurrence of bacteria in cultures made from the incipient and intermediate stages of decay is also of considerable interest. By the time the decay reaches the final stage, these bacteria apparently largely disappear. In only two cases were they observed in cultures made from the final stages of decay, and in both these cases a fungus was also present.

The presence of bacteria in decaying aspen wood has been previously reported by Eklund and Wennmark[25] who, in referring to certain culture experiments made by Dr. E. Melin, say in part, "It was, however, impossible to obtain cultures free from bacteria which outgrew the fungus so that it did not develop its typical characteristics. According to Dr. Melin, aspen wood is often heavily infected with bacteria."

Altho the bacteria found in connection with the decayed aspen wood were not studied microscopically, there is some reason to believe that in most cases a single organism was involved. Cloudy, slimy colonies were invariably formed on the malt agar culture medium used. Whether

[24] Münch, C. Über krankhafte Kernbildung. Ztschr. f. Forst-u. Landw. 8:533-547, 553-569. 1910.

[25] Eklund, S. and Wennmark, G. *loc. cit.*

or not these organisms play an important part in the progress of decay in aspen is a question well worth careful study.

In a way, one of the most disappointing and yet one of the most significant features of the cultural studies was the fact that it was quite impossible definitely to identify the fungi obtained by ordinary gross examination. In only a very limited number of cases were typical cultures of *Fomes igniarius* obtained. Altho most of the cultures here considered were made directly in the field, the number of contaminations was almost negligible. The fungi obtained, however, exhibited a great variation in cultural characteristics. Some grew rapidly, some grew very slowly, a few were a characteristic brown color, more a light yellow or cream color, almost every culture had some rather marked special characteristics.

The question naturally arises whether these cultures represent a large number of species of fungi or strains of one or two forms. Meinecke[26] in Utah, Eklund and Wennmark in Sweden, and others both in this country and in Europe report only three common fungi causing rots of aspen, namely, *Fomes igniarius, Armillaria mellea,* and *Fomes applanatus.* By far the most common of these three is *Fomes igniarius.*

Long and Harsch,[27] who made a very detailed study of the variation on vegetative characteristics occurring within a species of certain wood-destroying fungi, conclude that "the cultural characteristics of vegetative development of the various strains of a given species of fungus show no appreciable difference between cultures of this fungus whether obtained from infected wood or from sporophores. Neither do the hosts of the fungus seem to make any marked changes in the fundamental cultural characteristics when strains from different hosts are compared. There may be minor differences due to the host from which the strain came, but nothing more."

Schmitz,[28] on the other hand, found considerable variation both in the rate of growth and the texture of the fungus in different strains of *Fomes pinicola.* It is true that no variation in color was observed, but as the mycelium of this organism is white, variations are hardly to be expected.

In fact, it would be rather extraordinary if the wood-destroying Basidiomycetes did not show some well marked morphological and physiological variations from the normal condition. Recent work,[29]

[26] Meinecke, E. P. *loc. cit.*

[27] Long, W. H. and Harsch, R. M. Pure cultures of wood-rotting fungi on artificial media. Jour. Agr. Res. 12:33-81. 1918.

[28] Schmitz, H. Studies in wood decay V. Physiological specialization in *Fomes pinicola* Fr. Amer. Jour. Bot. 12:163-177. 1625.

[29] Leach, J. G. The parasitism of *Colletotrichum lindemuthianum.* Minn. Agr. Expt. Sta. Tech. Bull. 14. 1923. Christensen, J. J. Physiological specialization and mutation in *Helminthosporium sativum.* Phytopath. 15:785-795. 1925.

especially on the *Fungi imperfecti* and on the Basidiomycetes, show that in the species studied physiological variations are probably the rule rather than the exception.

Still more important in this connection, however, is the fact that, with two exceptions, the only fruiting bodies observed were those of *Fomes igniarius*. Trees showing the final stage of decay usually bore fruiting bodies of this fungus. Out of a total of 82 fungus cultures from 271 inoculations, 21 were typical *Fomes igniarius* and 3 exhibited doubtful characteristics. Many of the remaining cultures may be *Fomes igniarius* tho exhibiting more or less well marked variations in vegetative characteristics, and some are quite probably *Fomes applanatus, Armillaria mellea,* or other primary or secondary organisms.

HISTOLOGICAL STUDIES

Sections, 20 microns in thickness, were cut from the radial surface of blocks which formed a continuous series extending from the central portion of the final rot area outward through the black zone, intermediate and incipient stages of decay into the sound wood. Three methods of staining these sections were used: (1) Overstaining for 48 hours in an alcoholic solution of safranin, (2) Vaughan's Pianeze III b, (3) Herbert's safranin-picro analin. The best results were obtained with Herbert's stain, altho overstaining with safranin also gave excellent results. Mycelium was most commonly observed in the outer portions of the region of final rot, particularly in the black zone of *Fomes igniarius* rot. This observation agrees with the results reported by von Schrenk and Spaulding[30] who had no difficulty in finding the mycelium of *Fomes igniarius* in completely decayed wood. Kauffman and Kraber,[31] on the other hand, in their study of the heartrot of locust, did not observe hyphae in the black zone, altho they did find abundant evidence of its former presence.

That the mycelium was previously abundant in the portions of the final rot regions in our aspen samples was shown by the large number of hyphal punctures in the radial walls of the wood elements and also by the remaining scattered hyphae. These observations agree with the results obtained from the culture studies.

Outward from the black zone into the region of intermediate rot there is a marked difference in the abundance of hyphae. Mycelium was not found in any of the sections cut from wood in the incipient stage of decay. Negative results were also obtained from culture studies.

[30] von Schrenk, H. and Spaulding, P. *loc. cit.*

[31] Kauffman, C. H. and Kraber, H. M. *loc. cit.*

The filaments observed in the black zone are quite different in appearance from those observed in the typical final and intermediate stages of decay. In the vicinity of the black zone the filaments commonly run horizontally in the medullary rays and vertically in fibers. They are of relatively large diameter and branch profusely, while those in the final and intermediate stages of decay are very fine and seldom branch. This difference may be due to a difference in nutritive conditions or to different organisms.

Among the most interesting structures appearing in discolored aspen wood are the tyloses in the vessels. These are found in great abundance in all three stages of decay and there is always a very sharp, definite line between normal wood and that showing incipient decay. Are these structures caused by the fungus or are they associated with heartwood formation in aspen?

Hartig[32] states that when the wood of dicotyledonous trees is exposed by wounds the vessels become completely plugged by tyloses. Münch[33] attributes tyloses to the presence of products resulting from the process of decay which stimulate the growth and development of the parenchyma cells. Stevens[34] has described similar structures in catalpa sapwood influenced by the decay of *Polystictus versicolor* in closely neighboring tissues. In a rcent contribution by Zeller,[35] "Wood decay produced by *Trametes subrosea* has a marked influence on the neighboring sapwood. In the healthy sapwood of both peach and prune, wood tyloses are found scatteringly in the larger vessels of the spring wood only, none having been found in the smaller vessels of the summer growth. Where only three to six annual rings of sapwood separate the decayed cylinder within from the bark, tyloses were extremely numerous in the larger vessels of the spring wood in rings two or more years old. In fact, in prune wood especially, vessels of spring wood have been found nearly filled with tyloses, and tyloses were also numerous in the vessels of the summer wood. Where several annual rings separate the decayed heart and the last year's wood growth, the toxic influence of the decayed wood on the production of tyloses in vessels two or three years old is nearly as great as where the fungus is nearer."

"Such disturbances surely influence the normal physiology of a tree, bringing about a weakened framework, increasing the mortality of crop-producing wood, and causing increased susceptibility to winter injury. There are also indications that the lack of water conduction

32 Hartig, R. The diseases of trees. Eng. Ed. London. 1894.

33 Münch, E. Versuche über Baumkrankheiten. Naturw. Ztschr. f. Forst.—w. Landw. 8:389-408; 425-447. 1910.

34 Stevens, N. W. *Polystictus versicolor* as a wound parasite of Catalpa. Mycologia. 4:263-270. 1912.

35 Zeller, S. M. Brown-pocket heartrot of stone-fruit trees caused by *Trametes subrosea* Weir. Jour. Agr. Res. 33:687-696. 1926.

in wood having such an abundance of tyloses has a direct countributary bearing on the physiological disturbances in prune trees known as leaf roll, June drop of fruit, and early yellowing and dropping of leaves."

There is apparent unanimity of opinion among the investigators cited, that these tyloses are the result of the activities of wood-destroying fungi. It would be interesting to know if their presence in an infected aspen tree affects in a material way the physiology and growth of the trees.

It seems possible that the tyloses in decayed or partially decayed aspen wood may influence permeability to wood preservatives. If tyloses increase the resistance of the wood to treatment, wood intended for treatment should be intelligently selected.

Since the chemical properties of decayed aspen wood, with particular reference to its cellulose content, will be studied in detail in the near future, practically no attention was given to this phase of the problem in this study. Spaulding[36] found on *Populus* that the wood fibers of healthy wood in most cases had an inner supernumerary layer which turned blue with chlor-iodide of zinc. The rotted tissues were separated from the healthy ones by a narrow infiltrated zone. Just inside this zone of infiltrated cells the affected fibers were of very uniform thickness and the walls were decidedly thinner than those of the healthy wood where the cellulose was present. In rotted tissues the cell cavities were also larger than in the unaffected cells. In other words, the cellulose layer is more or less completely dissolved from the interior of the fibers and the secondary layer is delignified, while the cellulose skeleton is left to the last.

SUMMARY AND CONCLUSIONS

Aspen or popple (*Populus tremuloides*) is one of the most abundant and widely distributed trees in Minnesota. Its utilization, however, altho greatly on the increase, is complicated by the great prevalence of heartrot.

Three fungi are probably the cause of almost all the heartrot of aspen in Minnesota. By far the most important of these is *Fomes igniarius*. So prevalent is *Fomes igniarius* rot that it usually masks or conceals rot caused by *Armillaria mellea* and *Fomes applanatus*.

A study of 385 trees from 77 sample plots distributed throughout the range of the species in Minnesota showed that when the volume of final and intermediate rot is deducted, the mean annual growth of well stocked aspen stands on average sites culminates at about 40 years. If final rot only is deducted, the mean annual growth of aspen stands on average sites culminates at about 50 years. This seems to indicate, under

[36] Spaulding, P. Studies of the lignin and cellulose in wood. Mo. Bot. Gard. 17th Ann. Rept. 41-58. 1906.

extensive management, a pathological rotation of from 40 to 50 years for the production of mass products.

Three stages of decay were distinguished: incipient, intermediate, and final. At 70 years the total rot (i.e., incipient, final, and intermediate) affects 31.2 per cent of the merchantable volume of the tree; at 60 years 27.5 per cent, at 50 years 23.0 per cent, at 40 years 18.9 per cent, and at 30 years 14.8 per cent.

As wood affected by only incipient decay is probably not culled by any wood-using industry in Minnesota, the amount of intermediate and final rot is of greater practical importance. At 70 years the intermediate and final rot stages of decay include 20.5 per cent of the merchantable tree volume, at 60 years 15.7 per cent, at 50 years 11.4 per cent, at 40 years 7.8 per cent, and at 30 years 4.8 per cent.

If only the final stage of rot is considered, merchantable tree volume is reduced 9.1 per cent at 70 years, 4.6 per cent at 60 years, 2.4 per cent at 50 years, 1.3 per cent at 40 years, and 0.7 per cent at 30 years.

Branch scars are probably the most important avenues of entrance for wood-destroying fungi, but fire scars and insect injuries are undoubtedly contributing factors.

No evidence was found to prove that suckers are infected by the parent stump through the roots. Heartrot seldom extends any appreciable distance into the roots, but usually terminates in the base of the stump.

Two hundred and seventy field cultures made from decayed aspen wood showed that a fungus may usually be obtained from the final stage of decay. Bacteria were commonly obtained from the intermediate stage, while 85.5 per cent of the cultures made from wood showing incipient decay were negative.

Microscopic examination of decayed aspen wood shows the mycelium of fungi to be abundant in the black rings characteristic of the final stage of decay. Mycelia of fungi are also common inside of these rings, but rarely are they found very far outside of them (i.e., in the intermediate stage). Mycelium was not found in the incipient stage of decay in any of the microscopic sections examined.

The results of these studies indicate that if aspen is grown with adequate protection from fire on a 40- to 50-year rotation under average Minnesota conditions, decay will not be a very serious factor in its production.