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A STUDY OF THE SAPROGENICITY, AND FACTORS INFLUENCING DECAY, OF CERTAIN BROWN-ROT FUNGI ON WESTERN REDCEDAR HEARTWOOD TEST BLOCKS

School of Forestry

University of Idaho

Chester M. Southam

1941

Aug. 8, 2006

Dear Dr. Calabrese,

I have recently returned from living out-of-state for over six months and noticed one day that I had forgotten to send you a copy of Dr. Southam's master thesis. Although your paper for the Hormesis Society in which you mention Dr. Southam was presented some time back, I have decided to forward the thesis to you with the thought that even at this late date you would enjoy reading it.

I much enjoyed your paper and thank you for sending me a copy of it.

Best regards,
Trudy Southam

P.S. While unpacking boxes of books in my new home I came upon one that mentioned Dr. Southam's affiliation with Dr Ehrlich - in particular how my husband, as a young college student was advised by Dr Ehrlich to leave forestry and further expand his scientific studies. The book The Scientific Life, was written

by Theodore Berland and published in
1962 by Coward-McCann.

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The author wishes to acknowledge his indebtedness to Dr. John Ehrlich, director of this investigation, without whose cooperation and assistance the problem could not have been a success; to Mr. Victor Sellers for his constant interest in the problem and his many useful suggestions; and to members of the Department of Zoology for their assistance in photography.

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A STUDY OF THE SAPROGENICITY, AND FACTORS INFLUENCING DECAY, OF CERTAIN BROWN-ROT FUNGI ON WESTERN REDCEDAR HEARTWOOD TEST BLOCKS

Chester M. Southam

INTRODUCTION AND PURPOSE

Two of the principal rots of western redcedar (*Thuja plicata* D. Don) are brown cubical rots, one of the pocket type and the other continuous. Neither of these rots has yet been associated with its causal organism, although considerable work has already been done on the problem (Aust 1932, Eades and Alexander 1934, Sellers 1940) and is being continued at the University of Idaho Forest Pathology Laboratory.

It is the purpose of the present investigation to learn which known fungi are capable of rotting heartwood of western redcedar. From this it may be possible to reduce the number of species which must be considered as possible causes of these rots. It is also the purpose of this problem to study fundamental relations between various physical and chemical properties of test blocks and their susceptibility to decay.

An adequate survey of the literature of this problem has been presented by Sellers (1940).

EXPERIMENTAL WORK

METHODS AND MATERIALS

Fungi Chosen for Testing

Obviously, the only known fungi to be considered as possible causes of the brown cubical heartrots of western redcedar are those which are indigenous to its range, and which are known to cause a brown cubical rot in some tree. The following fungi answer these requirements and were used in this problem:

UIFP stock culture no.	Fungus
891	*Fomes officinalis* (Vill. ex Fr.) Faull = *Fomes laricis* (Jacq. ex Fr.) Murr.
850	*Polyporus sulphureus* Bull. ex Fr.
879	*Polyporus schweinitzii* Fr.
765	*Fomes pinicola* (Swartz) Cooke
753	*Fomes roseus* (Alb. & Schw. ex Fr.) Cooke
772	*Trametes serialis* Fr.
773	*Trametes subrosea* Weir
770	*Coniophora puteana* (Schum. ex Fr.) Karst = *Coniophora cerebella* (Pers. ex Fr.) Schr.
737	*Poria xantha* (Fr.) Lind. forma *crassa* (Karst.) Baxt.

A few other species of brown-rot fungi are also indigenous to the range of western redcedar, but were not used in the investigation because they are not conceded to be a possible cause of the cedar rots. *Poria incrassata* attacks structural timbers. *Lenzites saepiaria* and *Lenzites trabea* rot slash, but are seldom found in heartwood, or in a living tree. *Lentinus lepideus* is found only on slash and seldom enters the heartwood. A species of *Merulius* is reported to be a cause of brown cubical rot of western redcedar (Hubert 1931) but no information concerning it is available. *Trametes sequoiae* causes a brown cubical rot, but is usually confined to sapwood. It does not occur in Idaho.

Establishment of Cultures

The culture jars (fig. 1) were Ball brand, flat-sided, wide-mouth, pint capacity preserving jars with two-piece brass screw-caps. Into each jar was poured 20 milliliters of malt agar culture medium[1]. The jars were then capped,

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[1] 20 gm. Difco Bacto-agar
25 gm. Trommer diastasic extract of malt
1 liter distilled water

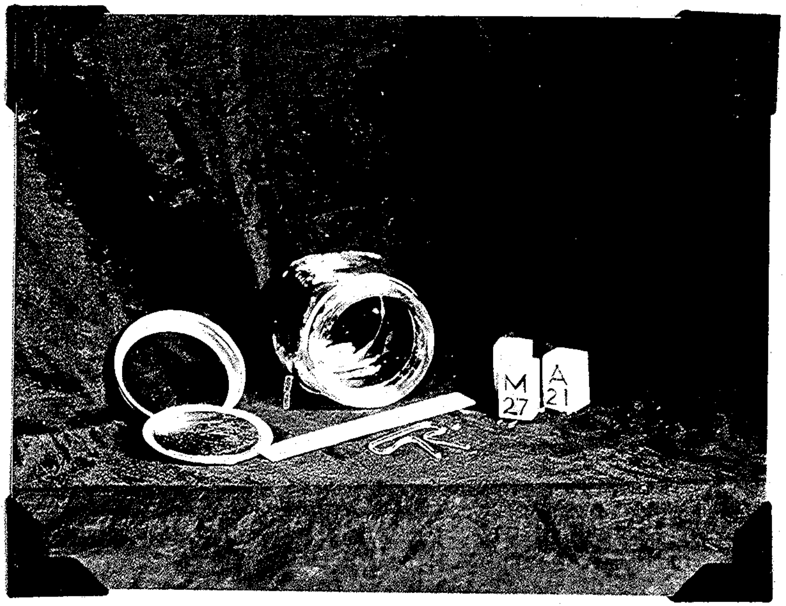


Figure 1. Showing blocks, culture jar and cover, and "T" support.

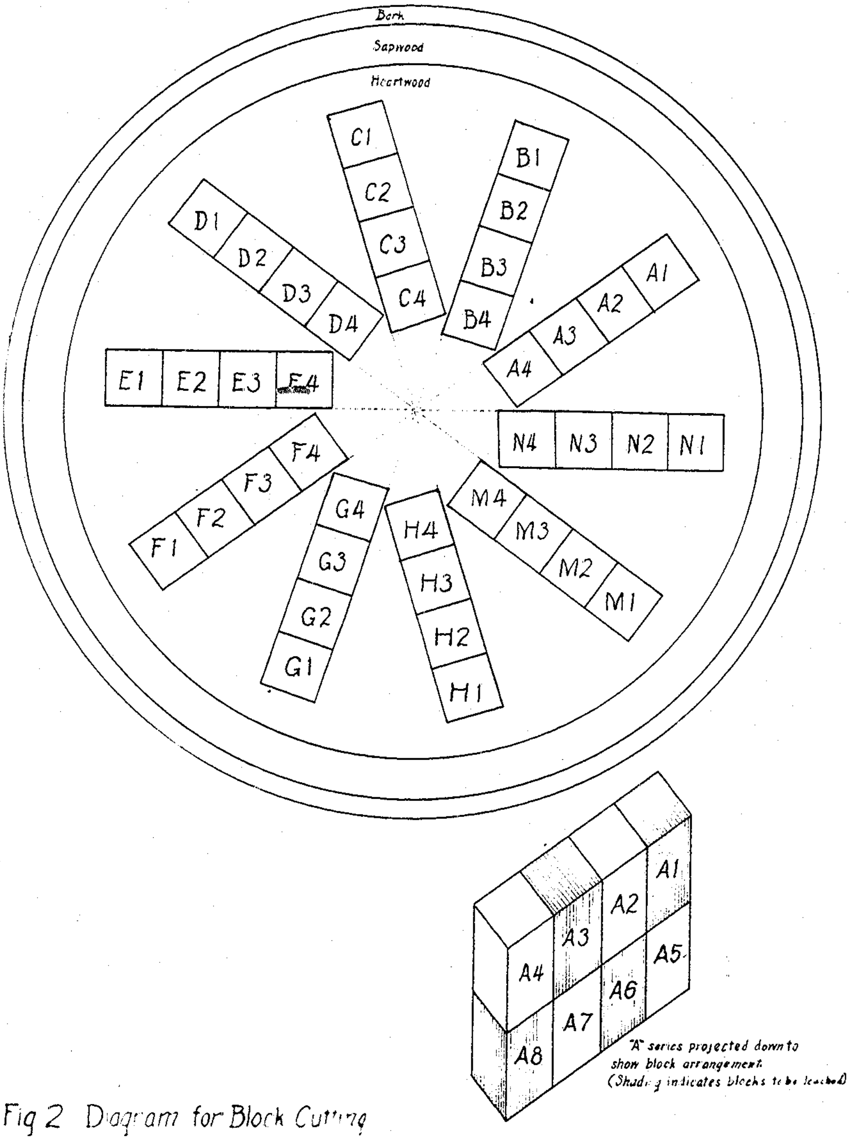
autoclaved, and laid on their sides to cool. Thus the opening was at the side, lessening the chances of aerial contamination during the subsequent manipulations.

Two weeks previous to the planting of these jars sub-cultures of the fungi to be tested were made in petri dishes. Transfers were taken from the periphery of these petri-dish cultures and planted in the appropriate labelled jars. One set of jars was not inoculated, but left for a control. The jars were then set aside for two weeks to allow the fungi to establish a vigorous growth.

Cutting and Numbering of Blocks

Since the primary purpose of this investigation was to determine the relative saprogenicity of the various fungi on western redcedar, it was necessary to have the test blocks as nearly comparable ("matched") as possible. However, it was suspected that cedar varies considerably in its susceptibility to decay from tree to tree, and even within a single tree. Therefore it was desired that the blocks should be representative of this probable range of variation. Accordingly, blocks from three trees were used in order to cover a representative range of variation, and the blocks from each tree were cut in such a way that variation should be at a minimum.

A transverse disk three inches thick was cut at approximately breast height from each of three trees at least eighteen inches in diameter at breast height. The method of cutting the test blocks from these disks is shown in figure 2. It seems axiomatic that little variation should exist within a given annual ring, or at least within a small portion of one ring. Therefore it is considered (see diagram) that the block most nearly comparable to A1 (for example) is A5 because these blocks are taken from the same annual rings in the same sector. Similarly, block B1 should be second in comparability to block A1 because these blocks are from the same annual



"A" series projected down to show block arrangement. (Shading indicates blocks to be leached)

Fig 2 Diagram for Block Cutting

rings, although from different sectors. Third in comparability to A1 is A2, because these blocks are from different rings in the same sector. All other blocks from the same sector should presumably follow A2 in degree of comparability to A1. Blocks from the other two trees should furnish an indication of the range of variation to be found among western redcedar trees.

Of the blocks which are most closely comparable (A1 and A5 in the example) one was intentionally leached and the other was left natural (as nearly natural as possible considering the subsequent treatment). This provided a close comparison between the action of a fungus on a natural block and its action on a closely comparable block which had been leached. The technique of leaching is given below.

The blocks which come second in degree of comparability (A1 and B1 in the example) were exposed to different species of fungi, thus permitting an accurate comparison of the effects of various species.

All blocks from a single sector (all A blocks for example) were exposed to the same fungus in order that a representative picture of the saprogenicity of each species might be obtained.

Blocks from the other two trees were used in the same manner, thus providing a large range of possible variation, giving a representative picture of each species' saprogenicity, and providing a large enough number of blocks for reliable interpretation of results. Table 1 shows which sectors were exposed to the various fungi.

Physical Characteristics of the Blocks

The number of annual rings per centimeter of radius was counted and recorded for each block. Hereafter in this paper the number of annual rings per centimeter radius is referred to as <u>ring density</u>. The volume of the blocks was also measured, using the mercury displacement method. From these volumes the specific gravity of each block was computed. In the case of leached blocks specific gravity was measured after leaching.

Leaching of Blocks

It is known that the great resistance of cedar to decay is caused by certain phenolic substances in the wood which have a toxic effect upon any saprogen (Schmitz 1922, Sowder 1929, Anderson and Sherrard 1933). Some, at least, of these substances are volatile or water soluble.

In this problem it is probable that most of the volatile substances were removed by oven drying. This is unfortunate in that the natural (unleached) blocks may have been less resistant to the attack of the fungus than undisturbed heartwood because of loss of these substances. This loss however could not be prevented, and it is even conceivable that oxidation of the blocks made them more resistant than is natural.

From half of the test blocks (with their proper numbers marked in india ink) the volatile and hot-water-soluble substances were completely removed by soaking in hot water (100° C.) with frequent changes until no noticeable concentration of the extracted material was removed after an hour's soaking. This was determined by the color and odor of the leachate. The blocks were hot-water leached for 40 hours, and between periods of heating they were left in cold water, spending a total of four weeks in water.

It is assumed that loss of these hot-water-soluble constituents had no effect upon the blocks other than to remove retardants or inhibitants to fungal activity. Thus, if this assumption be acceptable, it may be validly concluded that if a fungus caused excessive decay of leached blocks and gave indications of its ability to decay the natural blocks, than that fungus could be considered as a possible cause of a rot in western redcedar heartwood under natural conditions. It should be remembered that leaching is not entirely an artificial process. Exposed branch stubs and other wounds of living trees may be leached by rain, thus giving a saprogen a convenient threshold for further penetration.

Oven-drying and Weighing of Blocks

After the appropriate blocks had been leached and dried to a workable condition, all blocks, both leached and unleached, were sanded, trimmed, and brushed to remove all loose particles which might have fallen off during subsequent handling. They were then re-marked with india ink to clarify the original numbers.

All blocks were next dried to constant weight at 85° C. After cooling, the blocks were weighed to milligrams and all weights tabulated.

Establishing of Moisture Content and Sterilizing

Work done by Sellers (1940) indicates that the optimum initial moisture content for fungal growth is western redcedar test blocks is approximately 125 per cent. This moisture content was therefore used in the present problem.

The blocks were placed, in an upright position, in moisture chambers, enough blocks being placed in each chamber so that they could all touch the bottom and yet could not fall sidewise. The amount of water necessary to bring the blocks in each chamber to a moisture content of 125 per cent was then computed and added to each chamber. The blocks were allowed to soak at room temperature overnight in the covered chambers, and were then heated by flowing steam (atmospheric pressure) for one hour, both to sterilize the blocks and to increase the rate of absorption, and were then allowed to stand at room temperature until the water had all been absorbed.

It is admitted that the above method could, and undoubtedly did, cause considerable variation in the initial moisture contents, but the method was considered to be satisfactory for the purposes of this experiment. Another defect of this method of adding moisture is the slight leaching of the natural blocks during the process of absorption. No way of overcoming this defect has yet been devised.[1] This leaching might also tend to cause a positive

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[1] Rapid methods of getting moisture into wood are being tested at the University of Idaho Forest Pathology Laboratory.

error in weight lost due to decay, but such an error is considered to be negligible.

Exposure of Blocks

After the cultures had achieved a vigorous growth in the jars, and as soon as the moisture content of the blocks had been regulated, the blocks were exposed to the test fungi. Three blocks were placed in each jar, one on each end of a glass "T" (fig. 1) to support it from the surface of the medium. This prevented any leaching from or into the blocks. Each jar received either leached or unleached blocks, and had one block from each of the three trees. In this way, if any culture was not representative, the effect was evenly distributed.

One set of blocks was put into the uninoculated jars for controls in order that the effect, if any, of the incubation period could be observed.

The blocks were incubated at room temperature for nine months, and were subject to intermittent diffuse illumination. The caps were kept tightly screwed to maintain high humidity within the jars.

Disassembly

After the incubation period the blocks were removed from the jars. The appearance of the surface mycelium was noted, the mycelium (but no wood) scraped off lightly, the appearance and extent of the rot noted, the wet weight of the blocks taken as rapidly as possible following opening of the jars, and the blocks dried to constant weight at 85° C. When constant weight had been obtained the blocks were cooled and weighed to milligrams. Loss in weight and final moisture content were then computed. All raw data were recorded in a table (not shown), and all raw data on which the discussion and conclusions are based are repeated in table 1 of this thesis.

Tests on the Mycostatic Effect of Western Redcedar Extract

Schmitz (1922) and Sowder (1929) showed that the water extract from western redcedar heartwood is toxic to *Lentinus lepideus*. Anderson and Sherrard (1933) report that the extract (or at least a phenolic constituent of it) is toxic to *Fomes annosus*. However it is probable that neither of these fungi ever causes a rot of cedar trees, so in the present problem it was desired to note the effect of the extract upon fungi which might be the cause of cedar rots.

Four hundred grams of western redcedar heartwood sawdust were covered with 8 liters of distilled water and leached at 100° C. intermittently for 15 hours over a total period of three weeks. During this time the water was *never changed*, so that the leachate contained all of the substances extracted from the wood. The sawdust was removed, at the end of the leaching period, by means of a buchner suction filter and the leachate was saved. The volume of the recovered leachate was 6 liters, so that 15 milliliters of leachate represented the extract from 1 gram of wood. It was found by evaporation that one milliliter of the extract contained 0.00288 grams of solute (i.e. a 0.288 per cent solution). From this it is found that each gram of wood contributed an average of 0.0432 grams of solute (15 x 0.00288). This represents a loss in weight by leaching of 4.32 per cent. It is possible that this percentage is not the entire amount of substance removed by leaching because, although the evaporation was carried out at room temperature, some volatile solids might have been lost. On the other hand it is possible that some very minute wood particles might have passed through the filter, thus adding colloidal solids, not truly a portion of the extract, to the solution.

A series of culture media were made in which varying amounts of the cedar extract were used. These were made according to the usual formula for malt agar[1] except that for every milliliter of extract used, one milliliter

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[1] 20 grams Difco bacto-agar
25 grams Trommer's diastasic extract of malt
1 liter distilled water

of water was left out. Concentrations of 6 per cent, 4 per cent, 2 per cent, 1 per cent, and ½ per cent western redcedar extract were used. "One per cent" as used here means that the extract from one gram of wood (i.e. 15 ml. extract) was contained in 100 milliliters of medium.

All of the fungi used in the test block portion of this investigation were planted on each of these media. Cultures of *Lentinus lepideus* (UIFP stock culture number 534) and *Fomes annosus*[1] were also tested because previous workers have described the effect of cedar extract on these fungi (Sowder 1929, Anderson and Sherrard 1933), and it was desired to compare the results on these two fungi with the results on fungi which had never been tested previously. The growth of these cultures was noted after one week of incubation and again after two and three weeks. Their diameters of growth were compared with control cultures which were planted on plain malt agar medium, and the percentage of growth in comparison to the normal was recorded (table 4). For example, if a fungus on 4 per cent extract medium had grown to a diameter of 1 centimeter, while the control had grown to a diameter of 2 centimeters, that fungus was recorded as having a 50 per cent growth rate on 4 per cent extract medium.

PRESENTATION AND INTERPRETATION OF DATA

All of the raw data on which is based the interpretation of the saprogenicity tests is recorded in table 1. In table 4 is recorded the data concerning the mycostatic effects of the western redcedar heartwood extract.

Saprogenicity of the Tested Fungi

Control: No growth of any kind appeared in any of the control jars. In spite of this, changes in weight of the control blocks during the incubation period ranged from a loss of one and one-half per cent of the original oven-

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[1] Culture number 317 of the Forest Products Laboratory at Madison Wisconsin was used, the real identity of which is somewhat in doubt. However, this culture was formerly called *Fomes annosus* and it is probably the culture used by Anderson and Sherrard.

dry weight, to a gain of more than three per cent (table 1). The mean change in weight of all control blocks was a gain of one-tenth of one per-cent, with a standard error of the mean of plus or minus one-half of one per cent (table 2). It is obvious then that any variation in weight of the test blocks within these limits has no significance and must be attributed to experimental error. Such error might be caused by faulty manipulation, oxidation, leaching of soluble substances or imbibition of solutes in event that the block was touching the medium, or by unsuspected causes.

Fomes officinalis: On the natural blocks exposed to *Fomes officinalis* there was no appreciable growth of the fungus. A few strands of mycelium were noticed on blocks A15 and A12, but the changes in weight even in these blocks were well within the limits of experimental error, and no decay could be discerned.

On several of the leached blocks the fungus had grown, covering as much as one-half of the surface. However, only on block A1 was there a loss of weight which might be considered significant (4.58 per cent) and even in this block there was no macroscopically observable rot[1].

The fact that mycelium grew on the blocks without rotting them indicates that the lack of decay is due to inability of the fungus to attack the wood, rather than to any experimental difficulty. These results seem to demonstrate that *Fomes officinalis* is not capable of rotting western redcedar heartwood, even when its toxic content has been greatly reduced.

Polyporus sulphureus: Of the natural blocks exposed to *Polyporus sulphureus* only two supported any growth of the fungus. Of these, B14 had no observable rot and no significant change in weight. B15 was slightly rotted in one spot and showed a weight loss of 1.3 per cent. On the basis of the

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[1] Blocks which have been exposed to the action of each of these fungi will be examined histologically at a later date in order to observe any possible microscopic signs of decay.

data obtained from the control blocks, this loss in weight cannot be considered significant, but the fact that it was accompanied by a slight observable rot would seem to lend it importance.

The leached blocks were all well covered by the fungus, and (with the exception of blocks 83 and 818 on which the mycelium was very thin) they were well rotted. Weight losses ranged from 6.62 per cent to 48.53 per cent (table 1) with a mean of 17.0 per cent (table 2).

Since *Polyporus sulphureus* causes such extreme rotting of leached blocks of western redcedar heartwood under the conditions of this experiment, it seems safe to assume that the fungus could cause extensive damage to western redcedar heartwood which has been leached by natural climatic conditions. The very slight decay caused on unleached block 815 might indicate that this fungus is capable of rotting the natural heartwood in the living tree under certain favorable conditions.

Polyporus schweinitzii: None of the natural blocks became infected by *Polyporus schweinitzii*. Three of the blocks showed a weight loss over one per cent, the highest being 1.61 per cent, but obviously this must be attributed to experimental error. Failure of the fungus to grow on any of the natural test blocks might be attributed to the growth habit of the culture which was used. Only a very thin layer of mycelium was formed on the medium until the edge of the container was reached. There the fungus put out the dense fluffy mycelium which is characteristic of it, but many of the blocks were not situated so as to touch this mycelium.

Several of the leached blocks supported growth of this fungus, with as much as half of the surface showing decay. Weight losses were as high as 12.1 per cent (table 1). Failure of the fungus to grow on the rest of the leached blocks might be attributed to the growth habit of the culture which was used, as explained in the preceeding paragraph.

These results show that Polyporus schweinitzii is capable of rotting leached heartwood of western redcedar, although its degree of saprogenicity is not as great as other of the tested fungi. It produced no decay of the natural heartwood in this experiment, but a definite conclusion regarding its saprogenicity on natural heartwood must be withheld because of the growth habits of the culture.

Fomes pinicola: Fomes pinicola did not grow on any of the natural test blocks. The weight losses, however, were considerably higher (as much as 3.13 per cent) in these blocks than in any other blocks. This loss in weight is inexplicable.

Five of the leached blocks were attacked by this fungus, with resultant weight losses ranging from 2.76 to 66.97 per cent. There were, however, seven of the leached blocks which did not support any growth of the fungus.

The results seem to indicate that Fomes pinicola is able to cause extreme decay in leached western redcedar heartwood, but that usually its saprogenicity is low.

Fomes roseus: Natural blocks exposed to Fomes roseus were not decayed. On two of the blocks (N7 and N14) a few strands of mycelium could be seen, but there was no apparent effect on the blocks. One block had a weight loss of 2.16 per cent, but since it supported no fungal growth this loss is obviously insignificant.

This fungus grew on only three of the leached blocks, and on these covered not more than half the surface. In these blocks however the degree of saprogenicity was appreciable, weight losses of 15.7 per cent, 24.44 per cent, and 26.82 per cent being recorded.

Although Fomes roseus is capable of rotting leached western redcedar heartwood under certain experimental conditions, it seems improbable, from the experimental evidence, that this fungus could rot heartwood of the living tree.

Trametes serialis: No growth of *Trametes serialis* was found on the natural test blocks. All changes in weight were within the limits of experimental error indicated by the control blocks.

In leached blocks extreme decay was produced by this fungus. By the end of the nine-months incubation period every block was covered by a dense mat of mycelium, and decay was apparent in every block. Weight losses ranged from 3.36 per cent to 59.93 per cent (table 1) with a mean of 28.5 per cent (table 2).

Trametes serialis could undoubtedly decay heartwood of western redcedar which had been exposed to rain or other conditions which would leach out the toxic materials[1]. Hence we would expect to find this fungus decaying weathered cedar posts, shingles, etc., and it is conceivable that the fungus might attack heartwood of a living tree if it could gain entrance to the heartwood by way of a branch stub or other wound which had been leached by rain (see discussion, page 26). This same reasoning is, of course, equally applicable to any other fungus which is capable of rotting leached western redcedar heartwood.

Trametes subrosea: None of the natural blocks exposed to *Trametes subrosea* showed any visible rot, nor did they have a weight loss of significance. A few strands of mycelium were found on the bases of two blocks (H2 and H7), but apparently these had no effect on the wood.

Half of the leached blocks were attacked by this fungus, with resultant weight losses ranging from 14.21 per cent to 60.29 per cent. Surpriz-

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[1] The leached blocks of this experiment were leached by hot water, which might concievably remove different substances from the wood then cold rain water. However Bowder (1929) has demonstrated that cold water leaching does remove toxic constituents from western redcedar heartwood, so branch stubs which have been exposed to weathering are undoubtedly lowered in resistance.

ingly, the growth of this fungus on the surface did not always indicate an observable decay, for even though blocks H26, H23, and H28 were almost completely covered by the mycelium, there were no significant changes in weight of these blocks, and no rot could be observed.

It is hardly possible to interpret the results caused by this fungus. It is obviously capable of producing extreme rot in the leached heartwood of western redcedar, and yet it may cover the surface of a block without causing any rot.

Coniophora puteana: The mycelium of Coniophora puteana never grew onto, or even into contact with, the natural test blocks which were exposed to it. In spite of this, weight losses as high as 4.57 per cent were recorded for these blocks, and the average of weight changes occurring in all the natural blocks exposed to this fungus was 2.36 per cent, which is more than any single weight loss in the control blocks. No satisfactory explanation of this weight loss can be reached.

Nearly all of the leached blocks were decayed by this fungus. Blocks M6, M16, and M26 were the exceptions, and they were all in the same jar. The mycelium grew sluggishly in this one jar, whereas in the other jars containing leached blocks the culture was vigorous. The reason for the sluggish growth in this single jar is unknown. Of the blocks which were decayed, weight losses ranged from 1.1 to 49.32 per cent (table 1). Average weight loss of all leached blocks was 24.0 per cent (table 2).

The interpretations of the results obtained with Trametes serialis might also be applied to these results obtained with Coniophora puteana. That is: there is no doubt that Coniophora puteana can decay the heartwood of western redcedar after the toxic substances have been removed by water leaching, and consequently, it is conceivable that this fungus could gain entrance to the heartwood of a living tree through a weathered branch stub and eventually even work its way into the natural heartwood.

Poria xantha: Only one natural block (N24) supported a slight growth of *Poria xantha* forma *crassa* on its base. The same part of this block was slightly punky, which is taken as an evidence of decay. The weight loss of this block was 1.02 per cent.

Most of the leached blocks exposed to this fungus were partially covered by it. However, in comparison with the other fungi tested, its degree of saprogenicity is low. Weight losses of the blocks supporting the fungal growth ranged from 0.730 per cent to 14.5 per cent.

Poria xantha forma *crassa* is apparently capable of rotting the leached heartwood, and possibly the natural heartwood, of western redcedar under certain favorable conditions, although its relative saprogenicity on this wood is low. However, other considerations than this make it almost certain that this fungus could not be the causative organism of the common brown cubical heart rots of western redcedar (see description of the macroscopic appearance of the rot produced by this fungus, page 18).

Macroscopic Characteristics of Rots Produced in Western Redcedar Test Blocks by the Test Fungi

Control: There was no change in color of the control blocks during the incubation period.

Fomes officinalis: No macroscopically detectable rot was produced in the western redcedar test blocks by *Fomes officinalis*, even in those blocks on which mycelium grew. Apparently this fungus in incapable of decaying western redcedar heartwood.

Polyporus sulphureus: The blocks decayed by *Polyporus sulphureus* were slightly darkened. They were definitely brown, but not the dark rich brown which is characteristic of the continuous butt rot of western redcedar. The color approached that of the pocket trunk rot of western redcedar, although it was not quite as dark as this. When dry the rotted wood had a metalic sheen.

The decayed wood was punky when wet and brittle when dry. Considerable shrinkage resulted, and a few cracks running both lengthwise (either between the rings or perpindicular to the rings) and crosswise were observed after drying.

Admittedly, this is not a typical picture of a brown cubical rot, either as to color or cracking. However, a consideration of the experimental conditions under which the rot was produced might necessitate other conclusions. The time required for the production of a typical (late stage) rot under natural conditions is not known; but it is evident that most rots found in living trees, and consequently used for descriptions and specimens, are the product of several years fungal activity. In contrast to this, the test blocks used in this experiment were exposed to the fungi for only nine months, and it is evident from a macroscopic examination of the blocks that the rots had not yet (in most cases at least) reached the late stage of decay. Consequently a detailed comparison of the rots produced in these test blocks with the natural rots would not be valid. Furthermore, the cracking resulting from decay of these test blocks cannot be expected to be identical with the cracks occurring in decayed wood in a tree or timber. These test blocks are of such a size that they can shrink as a whole with but little strain on the tissue, and consequently with but little cracking. In a large volume of wood, such as in the living tree or a timber, the outer boundaries are more or less fixed, and consequently the strain caused by shrinkage can be compensated only by cracking.

Everything considered, the macroscopic characteristics of the rot produced in western redcedar test blocks by *Polyporous sulphureus* compare as closely as can be expected with the natural brown cubical rots of the heartwood of western redcedar, and especially with the pocket trunk rot. Its color and cracking are not directly comparable with the natural rots, but general appearance and friability indicate irrefutably that the rot produced by this fungus is of the brown cubical type.

Polyporus schweinitzii: The rot caused by *Polyporus schweinitzii* was light brown--slightly darker than that caused by *Polyporus sulphureus*. Its color closely resembled that of the pocket trunk rot of living western redcedar trees, but was considerably lighter than the continuous butt rot. In all other characteristics the rots produced in test blocks by *Polyporus schweinitzii* and *Polyporus sulphureus* were indistinguishable.

Since the considerations applied to the rot produced in test blocks by *Polyporus sulphureus* apply also to this fungus (and to all other fungi) it can only be said that *Polyporus schweinitzii* produces a rot (in western redcedar test blocks) of the brown cubical type and comparable in color to the pocket trunk rot of the heartwood of western redcedar trees.

Fomes pinicola: A dark brown rot resembling the continuous butt rot of western redcedar in color was caused by *Fomes pinicola*. The rot resembled those caused by the two preceding fungi in all characteristics other than color. It was obviously of the brown cubical type.

Fomes roseus: The surface color of the blocks which were rotted by *Fomes roseus* ranged from no change to a light chocolate brown, but within the block the color was medium to dark brown. A narrow dark ring was formed in the wood at what appeared to be the limit of decay. The rot seemed, usually, to be concentrated in the central portion of the block causing a hollow space because of longitudinal cracking. Shrinkage was extreme. No transverse cracks were observed, although this is probably explained by the small size of the blocks.

The characteristics of the rot produced by *Fomes roseus* on the test blocks indicate that this fungus causes a brown cubical rot in western redcedar heartwood. However, the rots produced by the preceding species resemble the natural rots of cedar trees more closely than does the rot caused by *Fomes roseus*.

Trametes serialis: The rot caused by *Trametes serialis* was light brown, and was accompanied by extreme shrinkage. It was not strikingly different, in macroscopic appearance, from the rots caused by *Polyporus sulphureus* and *Polyporus schweinitzii*. That is, the rot was of the brown cubical type and resembled to some extent the pocket trunk rot of western redcedar.

Trametes subrosea: *Trametes subrosea* produced a rot very similar in macroscopic appearance to that produced by *Fomes roseus* (see p. 17). However, the surface of the rotted blocks was all chocolate brown in color and consequently there was no characteristic ring at the limit of decay.

Since the characteristics of the rot caused by this fungus do not resemble the natural rots of cedar as closely as do rots produced by other of the tested fungi, it seems improbable that *Trametes subrosea* is a cause of a common natural rot of western redcedar trees.

Coniophora puteana: The test blocks which were decayed by *Coniophora puteana* were a peculiar mottled grey-brown in color. There was extreme shrinkage, and the decayed wood was brittle when dry. Cracks were common running lengthwise in the blocks, and occassional transverse cracks were observed.

The rot caused by this fungus in western redcedar heartwood test blocks is undoubtedly of the brown cubical type, but the color would seem to eliminate it as a possible cause of a common natural rot of living western redcedar trees.

Poria xantha: The blocks decayed by *Poria xantha* f. *crassa* were slightly, but definitely, softened. There was a small amount of shrinkage, and occasional splitting along the annual rings was observed. However, there was no color change.

The lack of color change indicates that *Poria xantha* f. *crassa* acts differently in western redcedar heartwood than any of the other tested fungi, since this fungus acted on the blocks for the same length of time as all of the other species. It is to be realized that the "colorless" rot caused by this fungus may represent only an early stage of the rot which it produces, so we can not say that *Poria xantha* does not produce a brown cubical rot in western redcedar. Nevertheless, the fact that it acts so slowly makes it unlikely that this fungus could be a common rotter of western redcedar heartwood in living trees.

The rot produced by this fungus in the test blocks bears an interesting resemblance to a common sap rot of western redcedar, known in local pole yards, as "golden glow sap rot". This sap rot covers large areas of wood as a soft colorless rot, and takes on the brown cubical characteristics only in its very late stages. The facts that *Poria xantha* acts in this same way, and has been found in association with rotted sap wood of western redcedar (Baxter, 1936) suggests the possibility that it might cause a decay of western redcedar sapwood under natural conditions[1].

Although it is possible that Poria xantha might cause a brown cubical rot in western redcedar if sufficient time were allowed it, it is exceedingly improbable that this fungus could be the cause of the common brown cubical heart rots of the living tree.

Mycostatic Effect of the Hot-water-soluble Substances of Western Redcedar Heartwood

In this study the mycostatic effect of western redcedar extract was demonstrated in two ways. First: by exposing blocks from which the hot-

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[1] The causative organism, or organisms, of "golden glow sap rot" is not known. Work is now being done on this problem in the University of Idaho Forest Pathology Laboratory.

water-soluble substances had been removed, to the action of brown-rot fungi; and second, by noting the effect of the leachate upon fungi when it was mixed with a culture medium.

Lowered resistance of leached blocks: Table 2 shows clearly the lowered resistance to decay of the leached blocks. Average loss in weight is greater in the leached blocks in every group. Blocks exposed to *Trametes serialis* show the greatest difference—25.5 per cent average weight loss in the leached blocks, against no change in the natural blocks.

Effect of Extract upon Cultures: One week after planting it was found that a 6 per cent[1] concentration of hot water extract in malt agar medium completely prevented growth of seven of the twelve fungi which were tested. (A complete record of these data will be found in table 4.) The 4 per cent concentration prevented growth of only one species (*Fomes officinalis*) but definitely retarded the growth of all species. The 2 per cent concentration retarded growth of a few of the tested fungi, but others grew just as well or better than the controls. This was also true of the 1 per cent concentration. All plantings made on a ½ per cent concentration of cedar extract in malt agar grew just as well, or even better than, the controls. Of especial interest was *Fomes officinalis* which, although it had not grown at all on 6 per cent or 4 per cent concentrations grew two or three times faster on 1 per cent and ½ per cent concentrations than on the control medium.

Two weeks after planting the same general results were observed, although some of the previously static fungi had begun to grow on the highest concentration of cedar extract, and in general the fungi on the high percentage extract-agar were not as far behind the controls as they had been a week before. On the ½ per cent concentration it was very noticeable

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[1] The term "per cent" as used in connection with these tests is explained in "Methods and Materials" (page 9).

that most of the fungi were growing more rapidly than the controls, and none of them were inhibited. *Fomes officinalis*, *Trametes serialis*, and *Trametes subrosea* were especially noteworthy in this respect, these species showing a growth at least twice as great as that on the control plates.

After three weeks all cultures were growing well and rapidly on all except the 6 per cent concentration. In this highest concentration three cultures (*Coniophora puteana*, *Poria xantha*, and *Lentinus lepideus*) showed no growth and were presumably dead.

The mycostatic effect of the hot-water extract of western redcedar heartwood is definitely shown by the actions of plantings on the 6 per cent concentrations. Indubitably if higher concentrations had been used they would have been lethal to all of the tested species. The fact that after two weeks the fungi on the high concentrations of extract had begun to grow more rapidly than they previously had, and that after three weeks they were almost as large as the controls, may be taken as an indication that in time the fungi develop an immunity, or tolerance, to the extract. The increased growth-rate of the fungi on the ½ per cent concentration demonstrates that in very low concentrations this extract of western redcedar heartwood stimulates, rather than retards, growth. This phenomenon might be referred to as a ~~toxicotrophism~~ hormesis. In bacteriology a phenomenon similar to this is known in which extreme dilutions of inorganic germicides will cause stimulated bacterial growth.

Percentage of Hot-water-soluble Substances in Western Redcedar Heartwood: By a comparison of the average specific gravity of all leached blocks with the average specific gravity of all unleached blocks it was found that leaching had caused a weight loss of roughly 5 per cent. Upon evaporating a sample of the hot-water extract and weighing the solute, the extracted substances were found to represent approximately 4.3 per cent of the weight of the natural wood. Obviously neither of these methods are very accurate, but it is safe to say that the hot-water-soluble constituents of western redcedar heartwood represent between 2½ per cent and 5 per cent of the total weight of the wood.

Variation in Susceptibility to Decay

In a single tree: Although the blocks from any one tree which were exposed to a single fungus varied considerably in weight losses, this fact alone cannot be taken as an indication of intrinsic differences in the wood of a single tree because several external factors might also have affected the degree of decay (e.g. moisture content, vigor of the fungus, and possible unsuspected factors). However, blocks taken from the same tree, and even from contiguous positions, were found to vary extremely in ring density (e.g. blocks #27 and #28); and since it has been shown that susceptibility to decay varies with ring density (see below) it must be concluded that susceptibility to decay varies greatly within a single tree.

Among several trees: Among the three trees from which the test blocks were cut a marked and consistent variation in decay was observed. The blocks from Tree No. 1 were most susceptible, Tree No. 2 next, and those from Tree No. 3 were least susceptible. This is true not only of the all-block averages, but also for the blocks exposed to each fungus[1] (see table 2). Thus it is seen that among several western redcedar trees a considerable variation in susceptibility to decay may be expected.

Correlation between susceptibility to decay and ring density: Comparison of averaged weight losses (table 2) with averaged ring densities (table 3) shows that these two sets of data are, roughly, inversely proportional to

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[1] With the single exception of series M (exposed to Coniophora puteana) in which blocks from Tree No. 2 showed a slightly greater average loss in weight than those from Tree No. 1.

each other. This correlation is shown in the individual sectors (i.e. in the blocks exposed to each fungus)[1] and also in the all-block averages. Figure 5 illustrates this correlation. It will be noticed that the difference in weight loss is greater between Trees 1 and 2 than between Trees 2 and 3 (table 2), and the same is also true of ring density (table 3). This supports the conclusion that ring density is inversely proportional to susceptibility to decay.

When weight loss is plotted against ring density (graph not shown) for each block this correlation is not always evident. The blocks exposed to some of the fungi do show a fairly constant inverse-proportionality curve, but others show no correlation whatsoever. Apparently this is explained by the effect of the many experimental variables, such as moisture content, vigor of fungus, etc., which could not be sufficiently controlled in the individual blocks, but which varied in such a way that they balanced each other when averaged. Must refer to previous workers findings on correlations between ring density & decay, and specific gravity vs decay. Zeller [illegible]

Correlation between susceptibility to decay and (apparent)[2] specific gravity: Comparison of the averaged weight losses due to decay (table 2) with averaged specific gravities (table 3) shows a rough inverse proportionality between these two sets of data. Figure 6 illustrates this correlation. Two of the sectors (H, exposed to Trametes subrosea; and M, exposed to Coniophora puteana) did not follow this trend, and their deviation was great enough so that the all-block average does not show this inverse proportion-

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[1] The blocks exposed to Polyporus sulphureus (series 2) very from this in that Tree No. 3 shows a greater average loss in weight than Tree No. 2. The difference, however, is very small and does not seem to be of enough significane to necessitate a reconsideration of the above statement.

[2] "Specific gravity", as used in this report, is the ratio of the weight of a piece of wood to the weight of an equal volume of water. Obviously this volume includes not only the wood substance but also the air space within the cells. This ratio is somtimes called "apparent specific gravity" to distinguish it from the specific gravity of the wood substance only (without its included air space).

ality. However, the data indicate quite definitely that susceptibility to decay is inversely proportional to specific gravity, although this correlation is not as definite as that between ring density and susceptibility to decay. When weight loss of each block was graphed against its specific gravity (graph not shown) no definite correlation was evident, although the trend to an inverse proportion was indicated. The lack of a definite correlation is probably explained in part by the other uncontrolled factors affecting decay.

Correlation between ring density and specific gravity: Since ring density and specific gravity both tend to be inversely proportional to amount of decay, it would seem to follow that they are directly proportional to each other. In order to check this suspected relation these data (for each block) were graphed (fig. 3). This graph shows that a correlation does exist, although individual blocks vary extremely from the average. When the blocks of each ring density group are averaged a definite direct proportionality is found.

Relation of Final Moisture Content to Loss of Weight

When final moisture content was graphed against percentage loss in weight due to decay (fig. 7), it was seen that the greatest amount of decay usually occurred in blocks, having final moisture contents between 80 per cent and 160 per cent. Blocks H1 (exposed to *Trametes subrosea*) and G1 (exposed to *Trametes serialis*) were the exceptions to this rule in that they had moisture contents of 233 per cent and 316 per cent respectively and nevertheless showed extreme weight losses. It seems probable that these high moisture contents became established after extensive decay had occurred because it is known (Boyce 1938) that rotted wood tends, or at least is able, to absorb a great amount of water. Intake of water could have resulted from imbibition of water from the agar, although when the

may also W R C [illegible]
and thus [illegible]
contain over [illegible]
moisture [illegible]
[illegible]

blocks were removed from the jars no direct contact between blocks and agar was noticed. There was of course an indirect connection by way of the mycelium. Since no other explanation seems reasonable for the existance of such high moisture content in these two blocks, they are disregarded in making the "average curve" of the graph (fig. 7).

The above data seem to confirm Sellers' work (1940) in which he found 125 per cent to be the optimum (initial) moisture content for the growth of fungi in western redcedar heartwood. also confirm work of Snell 1921, 25

It was suspected that the ring density or specific gravity of the blocks might affect their ability to absorb or retain water. Therefore a graph of ring density vs. final moisture content was prepared. This showed that there was no relation between ring density (or specific gravity) and final moisture content.

DISCUSSION

DISCUSSION OF METHODS

Establishing of Moisture Content

Final moisture content varied extremely from the intended initial percentage of 125. This variation may have resulted during the incubation period due to imbibition of substances from the agar or differential evaporation from the blocks, however it seems more probable that the variation existed from the start of the incubation period as a result of unequal distribution of water during the process of establishing moisture content. The method of adding moisture to the blocks had another disadvantage in that it resulted in a slight amount of leaching from the natural blocks. However, there is no better technique available at the present time.

Block Cutting

The method of cutting blocks used in this problem provided a series of fairly well matched blocks, as well as giving a representative range of wood. However, as a result of data taken on these blocks, it is possible to make suggestions which might be of value in future test block experiments. The measurement of ring densities and specific gravities, and the relations between these factors and susceptibility to decay, make it apparent that the most closely matched blocks are those which are vertically contiguous. It was further noted that little variation occurs within a vertical distance of three inches. It is therefore suggested that for future work where matched blocks are needed, the entire series of blocks which are to be compared be taken from vertically continuous positions. If blocks having a small vertical dimension can be used it will be possible to obtain a considerable number of closely comparable blocks. Furthermore, if blocks are used which cover only a short vertical distance of the wood and rather great radial and tangential distances, each block will have a correspondingly larger area for exposure to the fungus, and by covering a large number of annual rings will be more representative in regard to decay susceptibility.

It has been suggested in "Data" (see Trametes serialis) that fungi which can decay leached western redcedar heartwood might be able to attach the heartwood of a living tree if they could gain entrance through a branch stub or other wound which had been leached by rain. If a fungus could become established in a weathered branch stub it is quite possible that as it grew into the wood of gradually increasing toxicity it could neutralize or remove the toxic constituents, or else develop an immunity or tolerance to them. Such an ability is indicated by the activity of fungi on media containing cedar extracts.(see page 21). If a test block could be made which would approach this natural condition it might be possible to get a more accurate picture of the saprogenicity of a given species, than is obtained by the use of leached and unleached blocks, or unleached blocks alone. Accordingly, a scheme has been devised by which the natural transition from leached to unleached blocks might be simulated.

It is proposed that in future test block experiments using western redcedar or other woods containing soluble toxic materials, the test blocks be cut diagonally into two pieces, and that the bottom one of these two halves be leached and the other left natural. When the experiment is set up the leached portion of the block should be introduced into the culture jar first, with the flat face downward. The unleached half of the block would then be fitted onto the top of it. In such a "block" a fungus would have comparatively little difficulty in becoming established in the bottom leached portion, and as it grew upward it would come into contact with the natural block. Having once become established in wood the fungus would have a much better chance of attaching the natural wood than if it had to grow directly from the agar onto the natural wood.[1] Figure 4 illustrates a type of block which would incorporate both of the above suggestions. Such a double block would probably closely approach the natural transition from leached to natural wood, because some of the toxic substances from the upper (unleached) half of the block would diffuse down into the leached half, giving a gradual transition from leached to unleached wood.

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[1] It was shown in the present problem that the fungi in the jars with natural blocks were suppressed, and in some cases killed, by the action of the vapors given off by the unleached blocks. After the blocks had been removed from the jars transfers were made from the culture medium to observe whether or not they were still viable. Four plantings were made of each of the tested fungi, two from the jars of natural blocks and two from jars of leached blocks, and of these only *Fomes roseus* from the jar of leached blocks, and *Trametes serialis* from jars of both leached and natural blocks were still viable. Undoubtedly if more plantings had been made more of the cultures would have grown, but the results obtained illustrate at least that the cultures were much attenuated because of their stay in the jars.

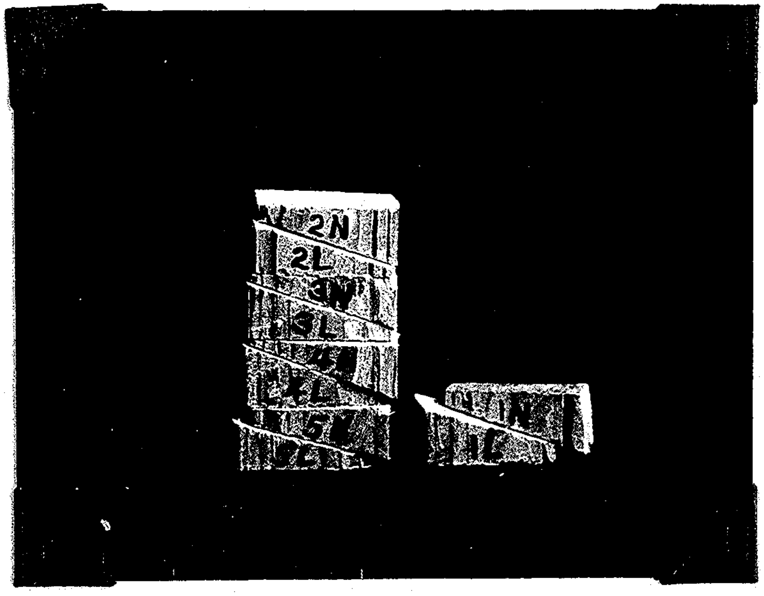

Figure 4. Suggested type test blocks for use in future saprogenicity tests with cedar or other woods having a high content of soluble toxic products. The blocks labelled "L" would be leached, and those marked "N" would be natural. See text, page 27.

DISCUSSION OF DATA

Saprogenicity of the Tested Fungi

In regard to saprogenicity the tested fungi may be divided into three groups; (1) those species which rot leached western redcedar heartwood and give evidence of ability to rot the natural wood, (2) those which rot the leached wood but are apparently incapable of attacking the unleached wood, and (3) those which apparently cannot decay the heartwood of western redcedar—either leached or unleached.

The first of these groups would seem to include *Polyporus sulphureus* and *Poria xantha*. The latter fungus, however, is quite definitely excluded as a possible cause of a common natural rot of western redcedar heartwood because of the macroscopic characteristics of the early stage of the rot which it produces.

Into the second group fall *Polyporus schweinitzii*, *Fomes pinicola*, *Fomes roseus*, *Trametes serialis*, *Trametes subrosea*, and *Coniophora puteana* all of which rotted only leached blocks. The contention that *Polyporus schweinitzii* is the cause of the common red-brown (continuous) butt rot of living western redcedar trees (Hedgcock 1914, and Boyce 1930) can neither be confirmed nor denied because of the unfortunate characteristics of the culture used in this test. It has not, however, as great a degree of saprogenicity as several of the other tested fungi. *Fomes pinicola* caused a rot which resembled the common red-brown butt rot of redcedar trees, but its relative saprogenicity was usually low. The possibility that this fungus might be the cause of a common cedar rot cannot be refuted from evidence obtained in this problem, even though it rotted none of the natural blocks. *Trametes serialis* caused such extensive decay of leached blocks that its possible role in cedar decay must not be overlooked. However, it is primarily a sap rot fungus in other trees, so it is probable that if it does attach western redcedar it affects only the sap wood. The fact that this fungus was found to be viable after nine months in a jar with natural blocks[1], and had not attacked the blocks at all is a very good indication that it cannot attach the natural heartwood. The characteristics of the rot produced in the test blocks by *Coniophora puteana* make it appear improbable that this fungus could be the cause of a common rot of a living redcedar tree. The relative saprogenicity of *Fomes roseus* and *Trametes subrosea*, and their macroscopic characteristics apparently indicate that they are not causes of common rots of western redcedar trees.

Fomes officinalis seems to be completely incapable of rotting western redcedar heartwood.

In any discussion of the saprogenicity of fungi on woods having highly toxic constituents, it must be remembered that both leached and unleached blocks present unnatural conditions for fungal attach. The leached blocks are so reduced in toxic content that they might act merely as a culture medium for the growth of almost any wood-destroying fungus. Unleached ("natural") blocks, on the other hand, not only tend to lessen the virulence of the attacking organisms because of their toxic vapors[2], but also they have an unnaturally high resistance to decay organisms because wood rotting fungi usually gain entrance to a tree through a wound which has been subjected to

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[1] After the blocks had been removed from the jars plantings were taken from the agar to see if the mycelium were still viable. Of the cultures from jars of natural blocks only *Trametes serialis* grew.

[2] It must be remembered that the cultures in the jars containing unleached blocks were probably suppressed or even killed because of the vapors given off by the natural cedar heartwood. Attempted re-isolation of the fungi after the incubation period confirmed this probability (see footnote 1 above). Such attenuated hyphae would not be expected to have the same saprogenicity as a vigorous culture. Hence, even if all other conditions had been equal, the natural blocks were exposed to less virulent cultures than the leached blocks.

weathering, and in the unleached test blocks the fungus is opposing the full resistance of the wood without the convenience of a threshold where it can become established before encountering the full concentration of toxic constituents. Reliable indications of saprogenicity by means of test block experiments with highly resistant woods await the development of a type of test block which more nearly similates natural conditions. A type of block which might be of value in such experiments is suggested above (page 27; fig. 4).

Mycostatic Effect of the Western Redcedar Extract

It has been found that not only is the hot-water extract of western redcedar lethal to fungi when used in sufficiently high concentrations, but also that in dilute concentrations it is a stimulant. The present problem also demonstrates that if a fungus is able to survive the toxic effects of the extract it will gradually overcome these toxic effects and grow vigorously. This fact might go far in explaining the ability of a fungus to rot natural cedar heartwood in spite of mycostatic constituents in the wood.

Variations in Susceptibility to Decay

Since ring density and specific gravity vary considerably among blocks taken from neighboring positions in a tree, and since it has been observed that both of these factors tend to vary inversely as decay susceptibility, it follows that various areas in a single tree may vary greatly in their susceptibility to decay. Extreme differences in susceptibility to decay are also noticed among different trees.

It has been suggested by previous authors (Hunt and Garratt 1938; USDA 1940) that variations in susceptibility to decay may be accounted for by variations in concentrations of toxic constituents. It is obvious from the present study that such an explanation cannot be the only one, for extreme variations have been observed among blocks from which all appreciable quantities of toxic materials have been removed by water leaching.

Since it has been found that there is a direct correlation between ring density and specific gravity, it is indicated that increase in ring size is usually the result of a proliferation of large spring cells without a proportionate increase in the small summer cells.(because if the proportion were constant then specific gravity would be constant for all ring densities). Stated more simply; blocks of low ring density consisted mostly of spring cells, and blocks of extremely high ring density ~~consist largely~~ have a greater proportion of summer cells. If this indication is a fact, then it could be stated that blocks having the greatest number of spring cells in proportion to summer cells are most susceptible to decay. Furthermore it was found that the summer cells have much thicker walls than the spring cells[1]. It is obvious then that blocks of high ring density (i.e. having narrow rings) have a comparatively great proportion of small thick-walled summer cells, and hence have a greater amount of wood substance than a block of equal size which has a low ring density. It may well be then that resistance of wood depends upon the amount of wood substance which opposes the entrance of the pathogen. In other words, the resistance may be mechanical rather than physiological.

The above discussion is not intended to refute the supposition that variation in decay susceptibility results from variations in concentration of toxic substances. It merely emphasizes that concentration of toxic constituents is not the only factor affecting variation in decay susceptibility, and that concentration of actual wood substance may be another reason for this variation.

There is a possibility that the increased resistance of blocks of high specific gravity and high ring density has to do with moisture content, because the small lumina of the summer cells would become filled with water,

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[1] Transverse sections of healthy western redcedar heartwood were cut and the thickness of cell walls measured. These measurements show summer cells averaging 6.0 microns in thickness and spring cells averaging 3.7 microns in thickness.

thus inhibiting growth of fungi from lack of air, at lower percentages of moisture content than would the larger lumina of spring cells. It seems improbable that this would often be the cause of the variation in decay susceptibility because it has been shown in the present investigation that marked decay can occur even when the blocks deviate widely from the optimum moisture content.

Moisture Content

Excessive decay can apparently take place in spite of wide deviations from the optimum moisture content.

It is worthy of note that no correlation was found between ring density (or specific gravity) and final moisture content. This seems to show that the thickness of rings (and hence cell size) has no relation to the ability of a block to retain water, for if ring size were related to water-holding capacity it is probable that the blocks would have shown this relationship after having had nine months for such an adjustment to come about.

The possibility that ring density might be correlated with the initial intake of water has not been investigated in this experiment.

SUMMARY

Leached and unleached western redcedar heartwood test blocks were exposed to cultures of nine fungi known to cause brown cubical decay in heartwood of western conifers. The saprogenicity of each fungus was determined, and the macroscopic characteristics of the rots were noted in an attempt to ascertain which of the tested species might be the cause of a natural rot of the heartwood of western redcedar trees.

A study was made of the fundamental interrelationships among specific gravity, ring density (number of rings per centimeter of radius), moisture content, and percentage weight loss (due to decay).

Suggestions are made as to the most useful type of test blocks for future saprogenicity tests.

The following conclusions were reached:

1. Of the tested fungi only *Polyporus sulphureus*, *Polyporus schweinitzii*, and *Fomes pinicola* are conceded to be possible causes of a rot of heartwood of living western redcedar trees.

2. Marked variation in susceptibility to decay exists among western redcedar trees, and within a single tree. Although variation may be partially dependent on concentration of toxic constituents, as previous authors have suggested, it is not entirely a result of such concentrations, but is related to ring density and to specific gravity of wood from which the soluble constituents have been removed.

3. Susceptibility to decay tends to vary inversely as specific gravity and ring density, although extreme deviations from this rule were observed.

4. Spring cells are probably less resistant to fungal invasion than are summer cells.

5. Ring density and specific gravity tend to be directly proportional to each other, although great variations in specific gravity are found among blocks of equal ring density.

6. The most closely "matched" blocks are those which are vertically contiguous.

7. Ring density has no apparent effect upon the ability of a block to retain moisture.

8. The optimum moisture content of western redcedar heartwood for optimum fungal activity is about 120 per cent throughout the growth period of the fungus. Variations of 40 per cent (plus or minus) from this optimum still permit fungal activity.

9. Western redcedar heartwood contains between 2½ per cent and 5 per cent of hot-water-soluble constituents.

10. In high concentrations the hot-water extract of western redcedar heartwood is strongly mycostatic to all of the common brown-cubical-rot-producing fungi, although if fungi are able to withstand the lethal effect of a given concentration of extract they seem to develop a tolerance, or immunity, to it.

11. In extreme dilutions, the hot-water extract of western redcedar heartwood stimulates, rather than retards, growth of the common brown-rot fungi.

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[illegible] 1921, 1925, 1929 on [illegible]

[illegible]? on [illegible]

[illegible] 1935 USDA [illegible]

Table 1--Pertinent raw data

Block number leached	Block number natural	Ring density	Specific gravity	Final moisture content[1]	Block surface covered	Percentage weight loss[2]
A1		4	.28	78.3	¼	4.58
A6		4½	.28	67.5	¼	1.2
A3		4½	.30	242.2	¼	-1.0
A8		6	.32	94.9	¼	.043
	A5	4½	.28	223.7	—	-1.85
	A2	4	.29	74.8	—	.22
	A7	5	.30	98.3	—	-.41
	A4	6	.33	69.2	—	-.01
A11		4	.29	223.9	¼	-1.2
A16		4½	.32	44.3	¼	.44
A13		5	.31	250.3	—	-1.5
A18		7½	.34	55.9	— —	.16
	A15	4	.32	111.	—	.54
	A12	4½	.33	139.	½	-1.1
	A17	5½	.32	154.6	—	-.65
	A14	7½	.37	65.7	—	.67
A21		7	.31	81.9	—	0.65
A26		6½	.30	30.2	—	1.0
A23		5½	.30	56.5	—	.84
A28		4	.30	62.1	¼	.83
	A25	6½	.32	160.7	—	.1
	A22	6½	.31	138.	—	.18
	A27	5½	.31	123.	—	.15
	A24	4	.30	103.	—	.06
B1		4½	.28	165.	all	41.60
B6		4½	.28	146.	all	48.53
B3		4½	.30	162.	½	.25
B8		5½	.31	266.	all	8.42
	B5	4½	129	211.9	½	-.94
	B2	4½	.29	243.4	¼	-.62
	B7	4½	.32	116.	—	-.97
	B4	5½	.32	115.	—	-.08
B11		4	.32	101.	all	20.45
B16		5	.33	73.2	¼	8.03
B13		6½	.36	110.	all	21.47
B18		7½	.35	92.9	¼	0.38
	B15	4	.32	72.6	¼	1.3
	B12	5	.35	65.3	—	1.1
	B17	6	.33	179.0	—	.18
	B14	7	.34	139.	¼	.08
B21		8	.31	175.7	¼	6.62
B26		8	.35	120.	¼	15.76
B23		6½	.33	73.3	all	18.58
B28		4½	knot.42	112.	¼	14.07
	B25	9	.32	191.7	—	.88
	B22	7	.32	113.	—	1.38
	B27	6½	.32	94.4	—	.70
	B24	4	.31	114.	—	.72

1. Final moisture content = $\frac{\text{final wet wgt.} - \text{final oven-dry wgt.}}{\text{final oven-dry wgt.}} \times 100$

2. Percentage wgt. loss = $\frac{\text{initial oven-dry wgt.} - \text{final oven-dry wgt.}}{\text{initial oven-dry wgt.}} \times 100$

Table 1 continued

Block number leached	Block number natural	Ring density	Specific gravity	Final moisture content	Block surface covered	Percentage weight loss
C1		3	.33	64.5	¼	12.1
C6		3	.30	156.	½	5.74
C3		3½	.31	87.4	--	.748
C8		5½	.30	87.0	¼	9.44
	C5	3	.34	115.	--	.854
	C2	3	.31	91.1	--	.84
	C7	3½	.31	74.4	--	1.3
	C4	5	.30	94.6	--	.22
C11		4	.30	201.1	--	-.35
C16		5½	.32	250.6	--	-.99
C13		6½	.33	174.9	½	8.31
C18		7	.34	168.9	--	-.28
	C15	4	.31	110.	--	.89
	C12	5	.33	55.3	--	1.61
	C17	6	.33	88.1	--	1.35
	C14	7	.34	71.7	--	191
C21		7	.31	161.6	--	.68
C26		7	.35	77.3	----	.93
C23		5½	.31	78.0	--	.99
C28		4	.33	121.	½	1.77
	C25	7½	.32	217.4	--	.38
	C22	6½	.35	128.6	--	.79
	C27	5½	.33	108.	--	.71
	C24	4	.30	134.	--	.55
D1		3	.30	86.5	--	.97
D6		3	.28	293.6	¼	-.63
D3		4½	.29	49.2	½	12.2
D8		5½	.30	114.	all	66.97
	D5	3	.28	130.	--	1.2
	D2	3	.28	77.7	--	3.03
	D7	3½	.30	87.1	--	4.63
	D4	5	.31	92.7	--	4.03
D11		5	.31	62.0	--	.66
D16		5½	.33	58.0	¼	6.67
D13		6	.32	232.0	--	-.16
D18		6½	.33	57.5	½	17.38
	D15	5	.32	127.	--	1.67
	D12	5½	.32	79.2	--	1.50
	D17	6	.31	75.0	--	1.1
	D14	6	.34	85.4	--	2.87
D21		7½	.32	79.4	--	1.0
D26		6	.32	38.3	--	2.19
D23		5	.32	68.6	¼	2.76
D28		4	.30	56.1	--	1.1
	D25	7½	.32	119.	--	2.27
	D22	6	.32	138.	--	1.57
	D27	5	.32	73.3	--	3.13
	D24	5½	.30	111.	--	2.92

Table 1 continued

Block number sealed	Block number natural	Ring density	Specific gravity	Final moisture content	Block surface covered	Percentage weight loss
E1		3	.29	101.	½	26.82
E6		3½	.29	56.0	—	7.25
E3		4	.31	84.2	½	24.44
E8		6	.33	88.6	½	1.1
	E5	3	.30	134.	—	.05
	E2	3	.29	72.7	—	.59
	E7	3½	.32	180.1	½	-.1
	E4	5½	.34	83.7	—	.05
E11		5½	.33	47.1	—	1.45
E16		5	.34	86.0	½	15.6
E13		6	.32	101.	—	.98
E18		6½	.34	70.5	½	1.3
	E15	5	.34	90.5	—	1.80
	E12	5	.33	94.3	—	1.67
	E17	6½	.33	84.6	—	1.42
	E14	5½	.36	138.	base	.98
E21		8	.36	68.6	—	2.41
E26		6	.34	68.4	—	1.6
E23		4½	.33	157.	½	.63
E28		9½	.33	100.	—	.75
	E25	7½	.33	158.	—	.94
	E22	6	.34	93.6	—	1.6
	E27	4½	.33	192.3	—	.1
	E24	8	.34	139.	—	2.16
F1		4	.31	162.		.50
F6		4	knot .41	41.7	no growth of any kind control blocks	.20
F3		4½	.30	176.		-.76
F8		4	.31	119.		-.1
	F5	4	.30	75.2		.61
	F2	4	.29	185.		-1.4
	F7	4	.29	83.6		.80
	F4	6	knot .36	53.7		.45
F11		4	.30	118.		-.54
F16		4	.33	58.2		-.57
F13		5	.31	260.		-5.12
F18		7½	.36	45.0		.40
	F15	4	.32	57.8		1.3
	F12	4½	.33	206.		-.96
	F17	5	.31	226.		-2.23
	F14	7	.34	64.1		.67
F21		7	.29	53.8		-.07
F26		5½	.32	62.7		.71
F23		4½	.32	81.3		.04
F28		4	.32	69.8		.91
	F25	7	.30	257.3		-1.96
	F22	5½	.33	199.0		-1.2
	F27	4	.31	77.5		1.51
	F24	4	.32	73.0		1.2

Table 1 continued

Block number leached	 natural	Ring density	Specific gravity	Final moisture content	Block surface covered	Percentage weight loss
G1		4½	.29	316.	all	51.90
G6		3½	.30	146.	all	5.34
G3		4½	.33	130.	all	43.64
G8		4	.32	150.	all	59.93
	G5	4½	.30	166.4	--	-1.5
	G2	3½	.29	178.	--	-.88
	G7	4	.33	65.6	--	-.05
	G4	5	.32	93.5	--	-1.3
G11		5	.32	93.9	all	31.38
G16		5	.34	114.	all	21.88
G13		4	.33	135.	all	6.16
G18		5	.34	123.	all	34.37
	G15	4½	.33	70.3	--	.96
	G12	5	.35	75.9	--	.37
	G17	5	.33	139.	--	.27
	G14	5	.34	144.	--	.51
G21		6	.30	234.3	all	5.95
G26		5½	.35	141.	all	3.36
G23		5½	.33	153.	all	33.02
G28		4½	.32	110.	all	44.29
	G25	6½	.32	193.6	--	-.67
	G22	5½	.33	151.6	--	-.14
	G27	5½	.34	99.0	--	.06
	G24	4½	.33	129.	--	-1.43
H1		4	.28	253.	all	44.29
H6		4½	.28	116.	all	60.29
H3		4	.31	126.	all	45.38
H8		5½	.34	155.	½	.77
	H5	4	.29	118.	--	.79
	H2	4	.29	222.8	base	-.47
	H7	4½	.32	123.	base	.56
	H4	5½	.34	122.	--	.06
H11		5	.31	52.8	¾	20.70
H16		5	.33	202.6	¼	.19
H13		6½	.37	93.9	all	14.21
H18		4	.31	114.	all	26.47
	H15	5	.32	197.9	--	1.76
	H12	4½	.36	90.6	--	1.84
	H17	6	.33	133.	--	1.5
	H14	3½	.32	106.	--	1.68
H21		7	.32	178.2	--	1.2
H26		6	.32	210.3	all	.26
H23		5	.33	110.	¾	-.01
[illegible]		4½	.33	143.4	all	.86
	H25	7	.33	150.1	--	.25
	H22	6	.34	91.6	--	1.34
	H27	5	.34	97.5	--	1.74
	H24	4½	.33	92.6	--	1.1

Table 1 continued

Block number		Ring density	Specific gravity	Final moisture content	Block surface covered	Percentage weight loss
leached	natural					
M1		4	.28	98.9	all	49.32
M6		3½	.30	85.7	—	1.5
M3		4	.30	129.	all	46.70
M8		6½	.31	295.2	all	5.13
	M5	3½	.29	121.	—	2.74
	M2	3½	.30	225.5	base	3.09
	M7	4½	.31	172.	—	.24
	M4	6½	.32	140.	—	.60
M11		4½	.31	89.6	all	35.51
M16		6 6	.33	87.5	all	32.63
M13		5½	.32	120.	¾	49.00
M18		7	.33	125.	—	1.0
	M15	4½	.32	125.	—	2.61
	M12	5½	.34	123.	—	2.04
	M17	5½	.33	165.	—	2.80
	M14	6½	.35	83.1	—	2.47
M21		7	.31	297.	all	1.1
M26		6½	.31	124.	—	1.4
M23		5½	.31	117.	all	39.61
M28		4½	.32	193.	all	25.42
	M25	7½	.33	189.8	—	2.48
	M22	6½	.32	133.	—	1.90
	M27	5½	.32	88.6	—	4.57
	M24	4½	.32	107.	—	2.80
N1		4	.29	69.3	¼	1.29
N6		3½	.28	80.5	¼	3.39
N3		5	.31	47.1	all	14.5
N8		7	.31	223. 47.7	¾	.357
	N5	3½	.29	47.4	—	.687
	N2	4	.29	203.	—	-2.50
	N7	5	.30	56.5	—	.619
	N4	7	.32	61.7	—	.366
N11		5	.32	153.	½	.996
N16		5½	.34	273.	½	-.257
N13		6½	.32	197.	½	.221
N18		6½	.35	38.8	all	8.40
	N15	5	.34	49.6	—	1.63
	N12	5½	.34	130.	—	-1.48
	N17	6	.33	75.1	—	1.00
	N14	6½	.34	95.0	—	.437
N21		7	.29	219.	[illegible]	.730
N26		6½	.31	37.1	[illegible]	1.54
N23		5½	.30	127.	[illegible]	1.78
N28		4	.31	159.	[illegible]	.945
	N25	7	.31	139.	—	.431
	N22	7	.33	152.	—	-1.39
	N27	5½	.32	103.	—	.294
	N24	4	.31	63.5	base	1.02

Table 2—Averaged percentage weight losses of all test blocks, oven-dry basis.

Species of fungi used	Sector	Tree No. 1		Tree No. 2		Tree No. 3		All trees	
		Leached	Natural	Leached	Natural	Leached	Natural	L.	N.
F. officinalis	A	1.3 4.5	-.51	-.51	-.15	.83	.0	.7	-.2
P. sulphureus	B	24.7	-.65	12.58	.68	13.76	.92	17.0	.31
P. schweinitzii	C	7.0	.8	1.67	1.20	1.09	.61	3.3	.9
F. pinicola	D	19.9	3.2	6.14	1.8	1.8	2.47	9.3	2.5
F. roseus	E	14.8	.2	4.8	1.47	1.4	1.2	7.0	1.0
CONTROL	F	-.1	.1	-.67	-.3	.40	-.1	-.1	-.1
T. serialis	G	40.20	-1.0	23.45	.53	21.66	-.55	28.5	.0
T. subrosea	H	37.68	.24	15.39	1.7	.6	1.1	17.9	1.0
C. puteana	M	25.7	1.07	29.5	2.48	16.9	2.94	24.0	2.36
P. xantha	N	4.89	-1.83	2.34	.397	1.25	.355	2.83	-.31
Averages (excluding controls)	all	19.6	.2	10.6	1.1	6.6	1.0	12.3	0.8

Table 3: Ring densities and specific gravities of leached blocks, averaged by sectors

Sector	Ring Density			Specific Gravity (after leaching)		
	Tree No. 1	Tree No. 2	Tree No. 3	Tree No. 1	Tree No. 2	Tree No. 3
A	4¾	5¼	5½	30	32½	31
B	4¾	5¾	6½	31	34	32
C	3¾	5¾	6	31	32½	32½
D	4	5¾	5½	29	32	32
E	4	5¾	7	31	34	34
F	4	5	5¼	30	32½	31½
G	4	4½	5¼	31	34	33
H	4½	5	5¼	31	34	33
M	4½	5¾	6	30	33	32
N	5	5¾	5½	30	33½	31
ALL	4½	5½	6	30	33	32

extract of western redcedar.

Fungus cultured	Concentration of extract in medium[2]									
	6%		4%		2%		1%		½%	
	7 days	14 days	7 days	14 days	7 days	14 days	7 days	14 days	7 days	14 days
F. officinalis	none	75%	none	100%	200%	120%	200%	200%	300%	200%
P. schweinitzii	none	50%	60%	80%	150%	150%	omitted	omitted	150%	120%
P. sulphureus	30%	75%	60%	100%	100%	120%	100%	120%	110%	120%
F. pinicola	none	30%	50%	60%	100%	100%	100%	100%	100%	100%
F. roseus	75%	75%	90%	80%	150%	120%	100%	130%	omitted	omitted
T. serialis	25%	60%	50%	100%	80%	120%	80%	300%	100%	300%
T. subrosea	50%	80%	80%	90%	110%	100%	80%	90%	125%	200%
C. puteana	none	none	50%	80%	75%	90%	omitted	Omitted	100%	120%
Poria xantha	none	none	50%	75%	100%	100%	100%	80%	100%	110%
L. lepideus	none	none	75%	90%	80%	100%	omitted	omitted	omitted	omitted
F. annosus	50%	100%	75%	100%	100%	120%	100%	100%	omitted	omitted

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1. $\frac{\text{Diameter of culture on extract medium x 100}}{\text{Diameter of control culture}}$ = percentage growth

2. For explanation of percentage strength of extract media see page 9.

__After the third week__ all viable cultures had grown so much that accurate measurements were impossible.

KEY TO LINES USED IN THE FOLLOWING FIGURES

Sector B	*Polyporus sulphureus*	— — — —
Sector C	*Polyporus schweinitzii*	— — — —
Sector D	*Fomes pinicola*	— — — —
Sector E	*Fomes roseus*	————————
Sector G	*Trametes serialis*	—— —— - - —— ——
Sector H	*Trametes subrosea*	—— - - — —— - - -
Sector M	*Coniophora puteana*	—— - - —— - - ——
Sector N	*Poria xantha*	- - - - - - - - - -
All Block Averages		━━━━━━━━

EXPLANATION OF FIGURE 3

Each dot represents a block. The circles designate the average specific gravity for each ring density. A leached block of ring density 9½ and a natural block of ring density 9 are disregarded in the average curve because the specific gravity of a single block cannot be considered to represent the average for its ring density.

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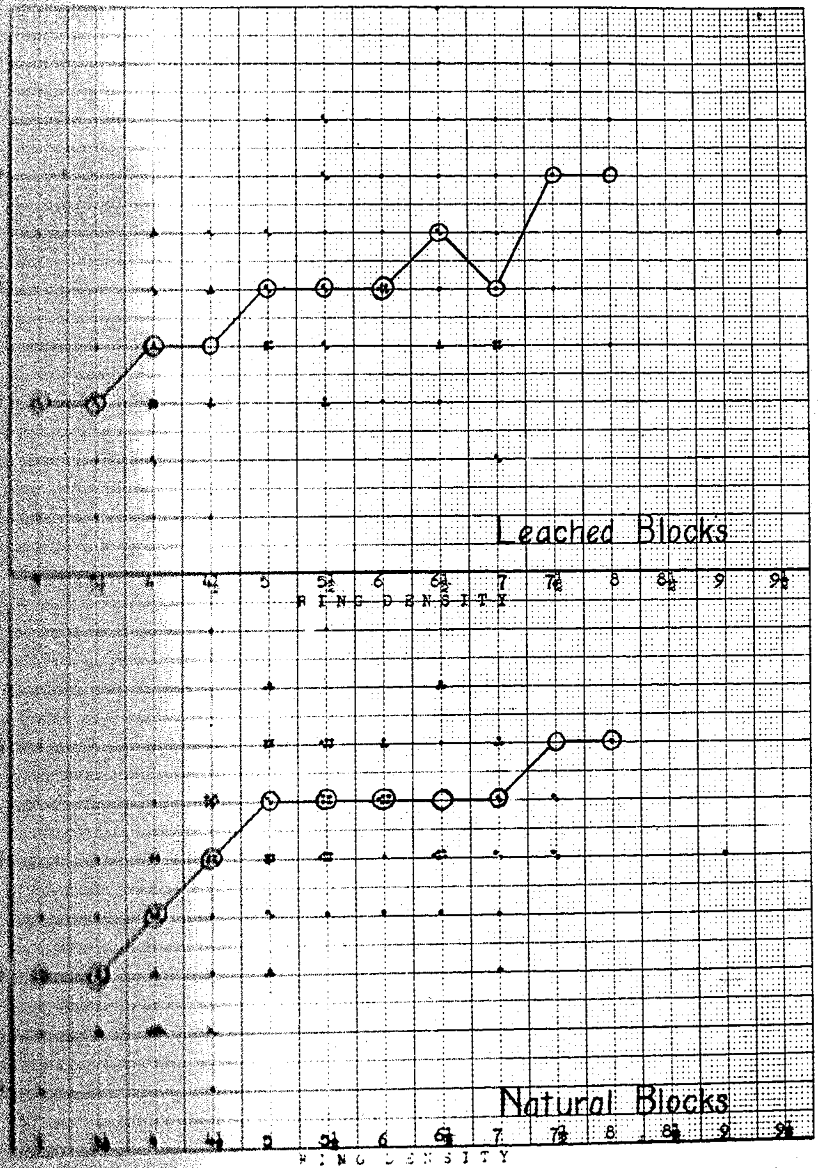

Fig. 2 Ring density vs. [illegible]

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Explanation of Figures 5 & 6

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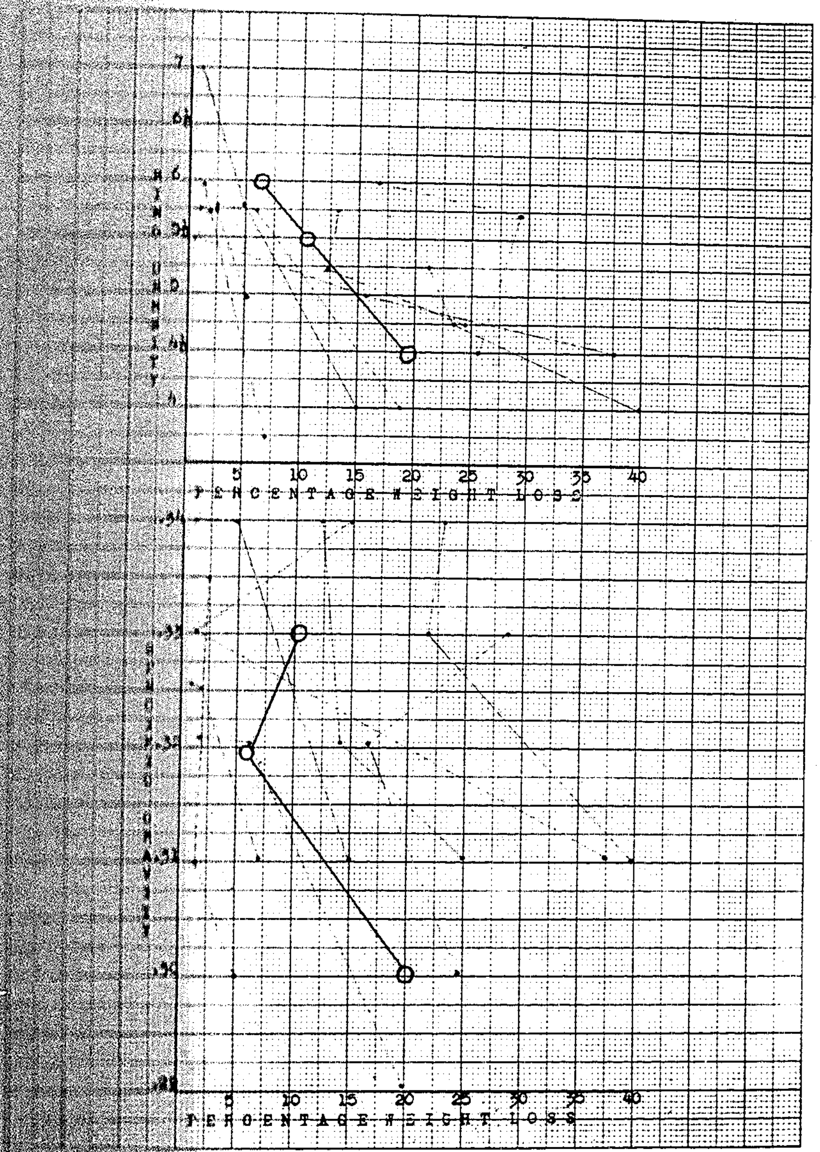

Figs. 5 and 6 Percentage weight loss *vs.* ring density and specific gravity

EXPLANATION OF FIGURE 7

The heavy black line designates the average curve for all blocks having weight losses over 4 per cent. The fine lines designate the average for each fungus (see key to lines page 44). The positions of the individual blocks are not shown. All averages were computed at 20 per cent intervals of moisture content.

The slight rise in the all-block curve at 260 per cent moisture content is undoubtedly insignificant, as there were very few blocks to average at that end of the curve. Two blocks having high moisture contents are disregarded in the graph, as explained in text, page 25 for all

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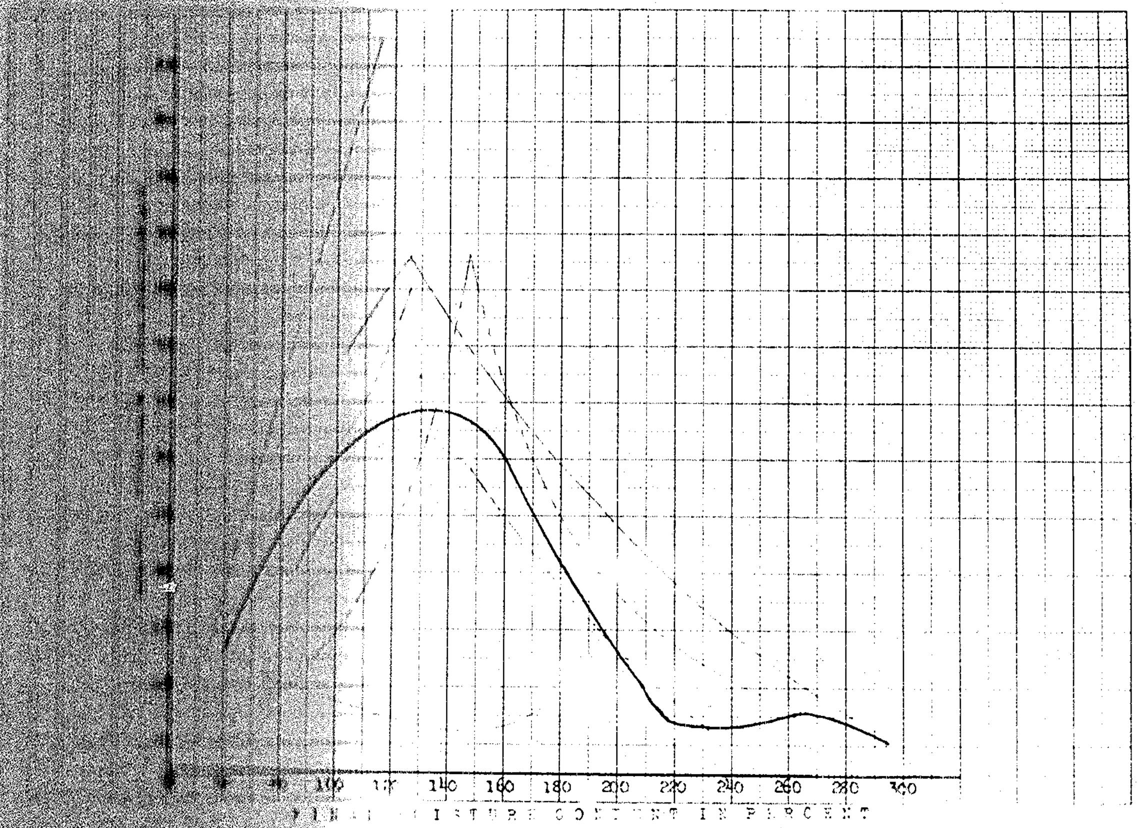
text, page 25.



[illegible] moisture content [illegible]