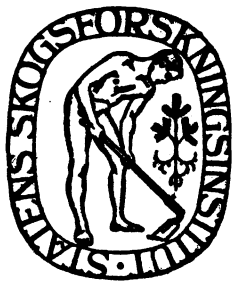

Studies in Fungal Decomposition of Pine, Spruce, and Birch Pulpwood

Studier över rötsvampars nedbrytning av tall-, gran- och björkmassaved

by

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Introduction

The biological deterioration of wood has been the subject of many investigations. Interest has generally been concentrated upon the influence of a particular organism on one or more species of wood (1, 6, 7, 8, 9, 10, 12, 13, 27, 28). In the following study an attempt has been made to observe the decomposition of naturally infected woods of the species *Pinus silvestris* L., *Picea abies* Karst., and *Betula pubescens* Ehrh. The microflora infecting forest timber through spores or other regenerative bodies have been allowed to continue their development in the wood under conditions as favourable and constant as possible. The deterioration present in the wood at a given time is primarily a result of the activity of the actual rot fungi and only secondarily a result of mould fungi and bacteria. By maintaining the temperature and humidity near the optimum conditions for wood-destroying organisms, it has been possible to have a high rate of decay, thus reducing the time for the experiment to tolerable proportions.

In the course of decay the following problems have been particularly studied: 1. the flora of wood-rotting fungi in the wood; 2. the moisture in sound and decayed parts of the wood; 3. the matter losses and changes in density; 4. the decomposition of the wood components lignin, pentosans, and cellulose; 5. the influence of decay upon the pulp yield and pulp quality (to be published later).

I. Experimental

Undebarked pulpwood logs, 2 metres in length and with a top diameter of 5—7 inches were cut as shown in Fig. 1. The pulpwood had been felled at the beginning of November in the Crown Park of Bogesund, a forest experimental area north-east of Stockholm. Pieces *1*, *4*, and *7* were placed undebarked in a

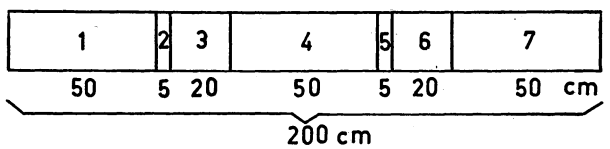


Fig. 1. Showing how the pulpwood logs were cut after felling. Pieces *1*, *4*, and *7* were placed in the rot-chamber. Discs numbers *2* and *5* were debarked and used for determination of the original densities. Pieces numbers *3* and *6* were used for determination of pulp yield and pulp quality of the sound wood.

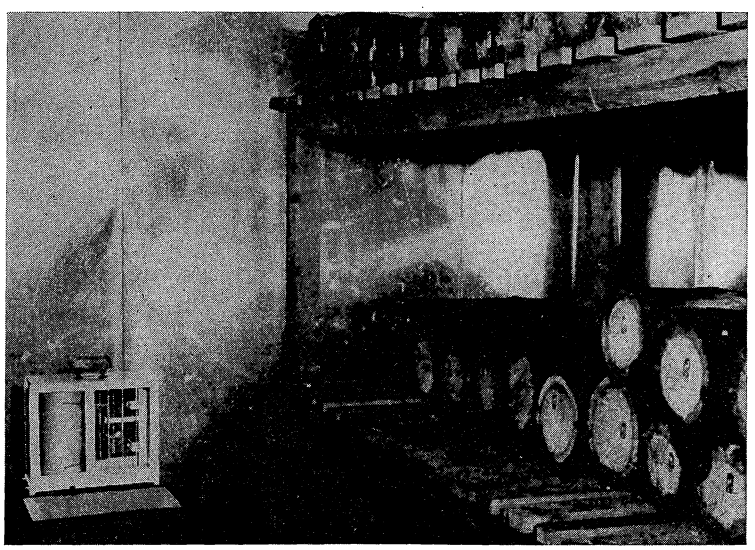


Fig. 2. The test material in the rot-chamber.

rot-chamber—Fig. 2—at a temperature of 20—22° C and a relative humidity of 98—99 per cent. These values are close to the optimum conditions for the growth and destructive power of most of the rot fungi (2). Discs numbers *2* and *5* were debarked and dried. Their densities were then determined by weighing and measuring the volumes of the absolutely dry discs. The volumes were measured according to a method described by Peterson and Winqvist in 1960 (25). Pieces numbers *3* and *6* were debarked and dried to be later used as sound test samples to be compared with pulp yields and pulp qualities of the decayed woods.

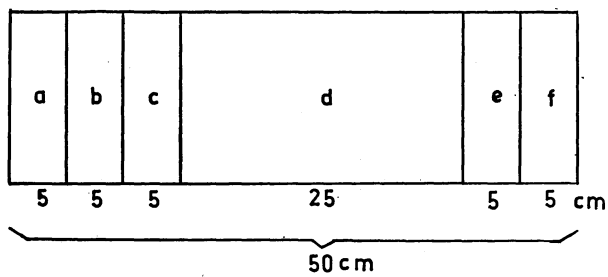


Fig. 3. Showing how a rotted piece of wood cas cut. The discs *a* and *f* were rejected. Discs *b* and *e* were used for the determination of the density of the rotted wood. Disc *c* was used for the studies of the spread of decay and for determination of the moisture content in decayed and sound parts of the wood. The piece marked *d* was used for determinations of the pulp yield and pulp quality of decayed wood.

After 3, 5, 7, 8, 9, 13, 15, and 17 months respectively, five pieces of each species of wood (pine, spruce and birch) were taken out of the rot-chamber and cut as described in Fig. 3. The end discs *a* and *f* were rejected. Discs *b* and *e* were debarked and dried and their densities determined. Discs *c* was used for studies of the spread of decay and for determination of the moisture content in decayed and undecayed parts of the wood. The piece marked *d* was debarked, dried and used for the determination of the pulp yield and pulp quality in the decayed wood.

II. Development of decay in the wood

The development of decay in the wood took place in somewhat differing ways in the coniferous and birch woods. In the latter the decay could first be perceived in a cross-section of a log as a number of small stains lighter than the surrounding sound wood, and slightly extending radially. This is shown in Fig. 4. With the aid of longitudinal sections it could be established that these lighter, rotted parts of the wood were narrow cones with their bases at the end surfaces of the log. This indicates that the infection had mainly spread from the end

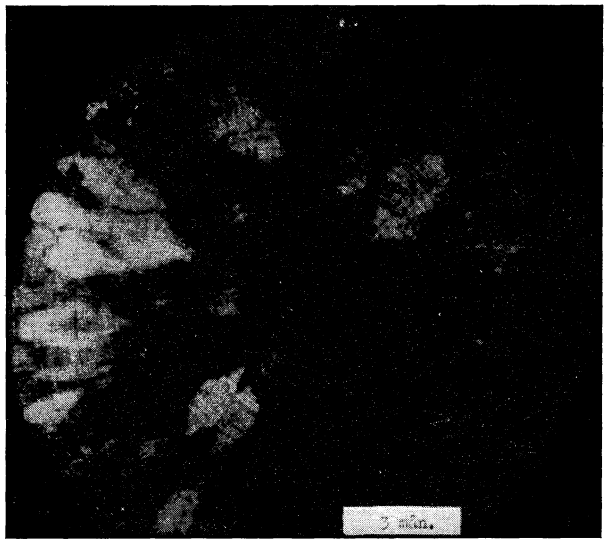


Fig. 4. Early stages of decay in birch pulpwood (3 months in the rot-chamber). The rotted patsr are lighter than the surrounding sound wood and slightly extended radially.

surfaces. In some cases the infection had also arisen in branch wounds or other injuries to the bark. The rotted parts of the wood extended rapidly and after 5—8 months they took up the whole cross-section. More or less strongly dark-coloured zones were then fully developed at the borders between the various rot

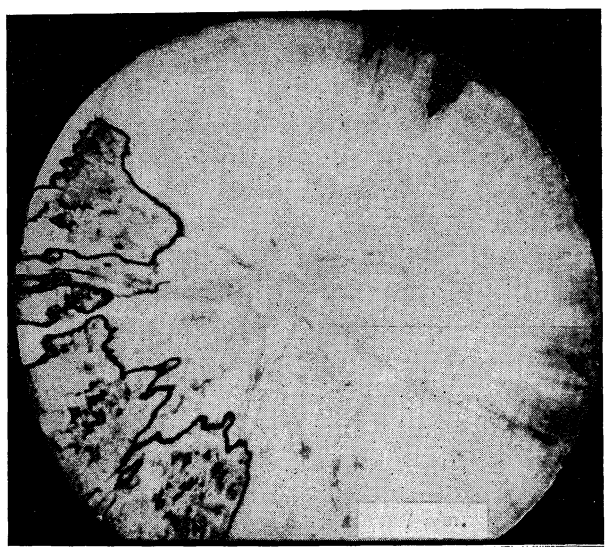


Fig. 5. Birch pulpwood afer 7 months in the rot-chamber. The whole log is rotted through and dark-brown zones are developep between the various rot cones.

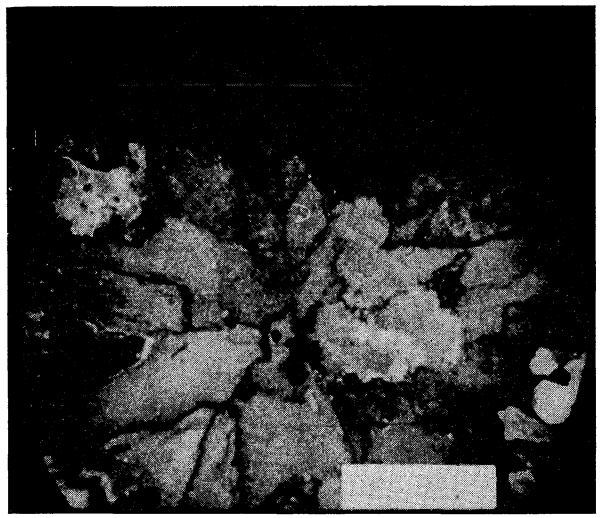


Fig. 6. Birch pulpwood after 13 months in the rot-chamber. The dark zones are still clearly visible.

cones. These dark zone lines are clearly seen in Fig. 5, and they remained in the wood even when the decomposition was extensive as shown in Fig. 6.

In coniferous woods the decay was discerned at fist as yellowish, brownish, or reddish dark sectors and stains in the sapwood. These discolorations usually extended towards the end surfaces indicating infection through these parts. No zone lines could be observed between the gradually uniting sectors.

III. Fungus flora in the test material

During the course of decay the fungus flora of the test material were investigated. Three methods proved satisfactory for identifying the rot fungi. 1. With the aid of an increment borer, sterilized in alcohol, increment cores were aseptically removed from the wood. The increment cores were placed in petri dishes with agar containing 2.5 per cent malt extract. The sprouting mycelia of rot fungi were isolated and the pure cultures identified using cultural and microscopical methods. 2. Some fungi such as *Polyporus abietinus* and *Coniophora puteana* could be induced to grow with surface mycelium if the wood pieces were left wrapped in moistened filter paper in plastic bags for some time. This method could be used to great advantage, when the wood was strongly decayed and the borer method then unsatisfactory owing to the brittleness of the wood or because of infections of bacteria and mould fungi. 3. Sporophores sometimes developed on end and mantle surfaces, when the wood pieces were placed in daylight and left to dry (see Fig. 7). The sporophores could then be easily identified. Table 1 shows the rot fungi occurring in the test material.

Table 1. Rot fungi occurring in the test material

Fungus	Occurring on		
	Pine	Spruce	Birch
Armillaria mellea (Vahl.) Fr.	×		
Coniophora puteana (Fr.) Karst.	×	×	×
Corticum laeve Pers.	×	×	×
Dædalia unicolor (Bull.) Fr.			×
Fomes annosus (Fr.) Cooke		×	
Lenzites betulina (L.) Fr.			×
Lenzites sepiaria (Wulf.) Fr.		×	
Peniophora gigantea (Fr.) Massee	×	×	
Polyporus abietinus (Dicks.) Fr.	×	×	
Polyporus adustus (Willd.) Fr.			×
Polyporus hirsutus (Wulf.) Fr.			×
Polyporus zonatus Fr.			×
Stereum hirsutum (Willd.) Fr.			×
Stereum purpureum (Pers.) Fr.			×
Stereum sanguinolentum (A. & S.) Fr.	×	×	
(Trichoderma sp.)	(×)	(×)	(×)

a. Pine and spruce

The fungus flora in the pine and spruce material respectively were almost identical. *Peniophora gigantea* was the most common species of the identified rot fungi on both pine and spruce, and it could be isolated from pine wood after only one month. This fungus, which causes an intermediate type of rot, is one of the most common fungi occurring on coniferous wood and on stumps of pine and spruce (11, 16, 17, 18). Wood attacked by *P. gigantea* shows a discoloration of the sapwood in the form of yellowish brown streaks running from the end surfaces of the log (11, 21).

Corticium laeve, which was not infrequently isolated from the test wood, is very common on both coniferous wood and hardwood and also on stumps of pine and spruce (17). Even in the early stages the fungus develops an abundance of resupinate fruiting bodies but causes only a slight decay of the white rot type in the wood (2, 4, 16).

Polyporus abietinus belongs to the common rot fungi in coniferous wood. As shown in Fig. 8, it grew readily with surface mycelium, when the wood pieces were kept moist in plastic bags. This fungus is very common and distributed all over Europe and North America and causes a typical corrosive rot in the sapwood of conifers and on stumps of pine and spruce (2, 4, 11, 17, 18). Wood attacked by *P. abietinus* is in the final stages soft, spongy, and very light (2, 11). This fungus can decompose both the cellulose and the lignin of the wood (13, 14). According to Campbell 1932 (10) the cellulose in sapwood of Norway spruce at a weight loss of 6.79 per cent had dropped from 60.54 to 55.08 per cent, the lignin content from 26.22 to 23.16 per cent and the pentosans from 10.28 to 8.87 per cent.

Stereum sanguinolentum was almost as common as *P. gigantea* in the test material. The former is considered to be the most common of the storage rot fungi on coniferous wood in Sweden, and it is widely distributed in Europe and North America (2, 11, 18, 24). The rot is of a corrosive nature and begins with a reddish discoloration of the sapwood becoming gradually browner. In the final stages it changes into a white pocket rot (2, 11). The fungus breaks down both the cellulose and lignin of the wood to about the same extent (24). *S. sanguinolentum* sometimes occurs as a wound parasite and can then cause top rot or marking rot.

Lenzites sepiaria was isolated from spruce in only one case. It is a common fungus on construction timber, on the trunks of dead conifers, and also appears on spruce stumps (2, 17). This fungus causes a brown pocket rot in the sapwood as well as in the heartwood (21). *L. sepiaria* rapidly decomposes cellulose (24) and pentosans. According to Apenitis et al. 1951 (1) 80—90 per cent of these wood components in spruce sapwood had been consumed at a weight loss of 64 per cent. The decomposition of lignin was considerably slower. For the same loss in weight not more than about 30 per cent of the lignin had been decomposed.

Armillaria mellea was identified on the pine by its characteristic rhizomorphs, which readily developed when the wood was kept moist in plastic bags (see Fig. 9). *A. mellea* is very common on conifer stumps (17), but it is perhaps best known as a parasite on plants and on growing trees, where it can cause serious damage. Growing saprophytically, however, it can appear as a genuin storage rot. It causes a decay of the white rot type, but in the incipient stages it attacks only the cellulose and the pentosans, while the decomposition of lignin does not begin until later (9, 10).

Coniophora puteana belongs to the fungi which developed surface mycelium in damp atmosphere (Fig. 7), and in this experiment it occurred on all the three species of wood. This fungus is best known as a cause of damage to woodwork in houses and cellars with poor ventilation, or where there is some leakage in water-pipes of from roofs (11). It is also common, however, on moist or improperly stored wood in the open (2). The rot is a typical destruction rot, the infected wood breaking up into cuboidal pieces. The decomposition of cellulose is very rapid and at a loss in weight of 68 per cent, according to Apenitis et al. (1), more than 95 per cent of the cellulose in spruce sapwood had been consumed. The decomposition of pentosans proceeded a little more slowly and the decomposition of lignin proceeded at a very slow rate. Thus, the lignin percentage in wood attacked by *C. puteana* will be considerably higher than in sound wood. This was also demonstrated by Gadd 1957 (13).

Fomes annosus was isolated from increment cores of some pieces of wood originally belonging to the same specimen of spruce. It does not belong to the

ostrage rot fungi, and it had undoubtedly been developing in the growing spruce as stem rot. It causes a typical white-spotted corrosive rot in the spruce heartwood.

The test samples of increment cores were freqently infected by mould fungi, primarily *Trichoderma* species, which had sometimes developed enormous sporemasses between bark and wood. In later stages it was noticed that *Trichoderma* mycelium grew within the sapwood. *Trichoderma viride* has proved able to decompose wood to some extent and may be classed among the soft rots. Experimentally it caused the following weight losses: spruce sapwood 1.1 per cent, pine sapwood 2.1 per cent, beech 1.0 per cent, and birch 5.1 per cent. Under the same conditions *Coniophora puteana* caused the following weight losses: spruce sapwood 66.8 per cent, pine sapwood 67.6 per cent, beech 61.1 per cent, and birch 66.7 per cent (20). Apparently, *T. viride* causes comparatively small losses in weight.

A number of various bacteria also occurred in the wood and infected the core samples making difficult the isolation and identification of mycelia of wood-rotting fungi. They already appeared after 2—3 months in the pine wood, but did not have an extensive effect until advanced stages of decay. Bacteria are considered not to have the power of decomposing the cell wall materials of wood, although there are several species that can decompose cellulose (34). There are, however, indications that wood deterioration may be caused by bacteria on material that has been buried in the earth or under water for a long time (11).

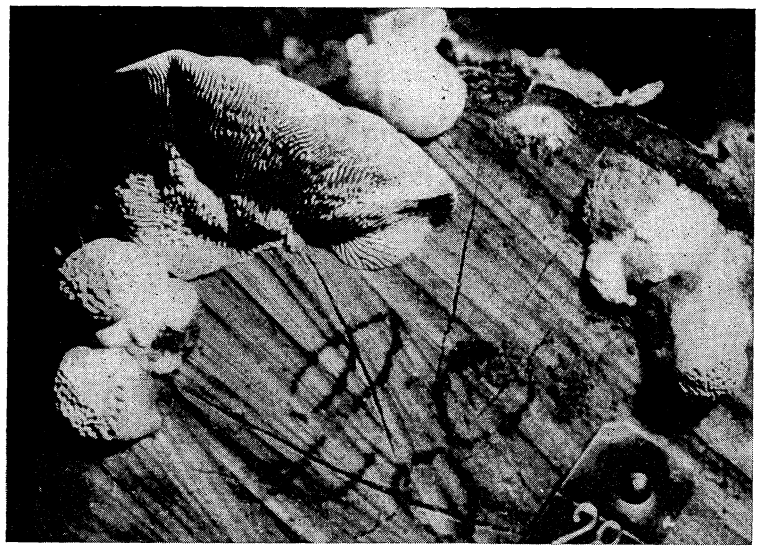
The coniferous wood in this experiment was attacked by our most common storage-rot fungi. Most of these cause corrosive rots of more or less typical kinds where cellulose and lignin are decomposed at about the same rate. Only two destruction rots (*Lenzites sepiaria* and *Coniophora puteana*) occurred in the test material, and of those the former was isolated only once. Nylinder and Rennerfelt (24) also found only one shrink rot in stored spruce wood, namely *Lenzites sepiaria*. *Armillaria mellea* was the only species of white rot fungi found on the coniferous wood in this material.

b. Birch

The fungus flora in birch wood were, as shown in Table 1, quite different to those of the coniferous wood. Only two wood-rotting fungi occurred in coniferous wood as well as in hardwood, namely *Coniophora puteana* and *Corticium laeve*. The former causes even in birch wood a destruction rot, and the latter causes a white rot.

The most common species in birch wood was *Polyporus zonatus*. According to Björkman 1953 (3) and 1958 (4) this fungus is very common on woods of

a



b

Fig. 7. Sporophores of *Lenzites betulina* (a) and *Polyporus zonatus* (b) developing on end surfaces of birch pulpwood.

aspen and birch, and the most severe storage-rot fungus on hardwoods in Sweden. It causes a rapid decay of the white rot type.

Lenzites betulina occurred very frequently in the test material. This fungus also causes a white rot on most hardwoods (11, 21) and is common on birch wood stored for a long time (4).

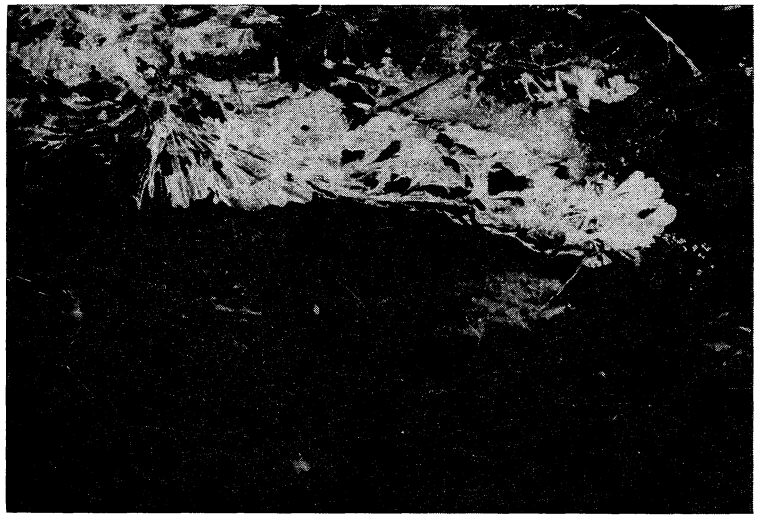


Fig. 8. Surface mycelium of *Polyporus abietinus* (upper) and *Coniophora puteana* (lower) growing on the bark of pine pulpwood.

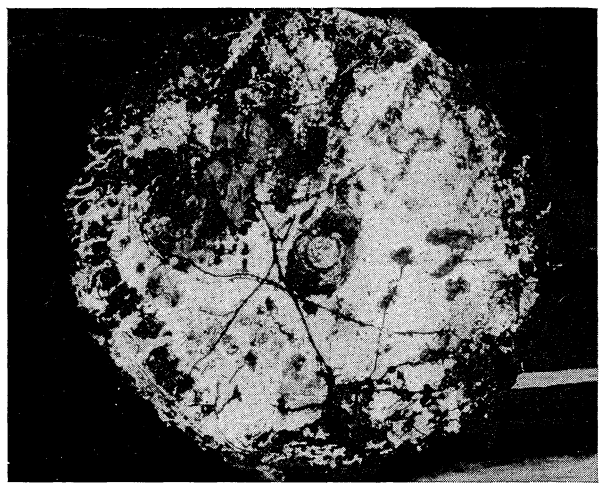


Fig. 9. End surface of pine pulpwood with characteristic rhizomorphs of *Armillaria mellea*.

Next to *P. zonatus*, *Stereum hirsutum* is probably causing the most severe damages in hardwood (4). In this material it was also relatively common. It causes a white stringy rot (11). Campbell 1931 (9) shows that in sawdust from oak sapwood, attacked by this fungus to a weight loss of 20.2 per cent, the cellulose content (based on weight of original oven-dry wood) was reduced from 58.8 per cent in the original sound wood to 49.0 per cent in the rotted wood. The lignin content had in the same wood dropped from 15.8 per cent to 11.3 per cent. Thus, *S. hirsutum* decomposes both the cellulose and the lignin.

Another common rot fungus in the birch wood was *Polyporus adustus*. It is very often occurring on all kinds of fallen hardwoods and causes a white rot. According to Campbell 1932 (10), which investigated beech wood attacked by *P. adustus* to a weight loss of 10.5 per cent, the cellulose content (based on weight of original oven-dry wood) had dropped from 59.5 per cent in sound wood to 53.1 per cent in decayed wood, the lignin content from 20.5 per cent to 18.0 per cent, and the total pentosans from 22.3 per cent to 19.8 per cent.

The remaining three rot fungi found in the birch wood of this material—*Daedalia unicolor*, *Stereum purpureum*, and *Polyporus hirsutus*—are all causing more or less typical white rots (3).

In addition to the examples above it can be of interest to give some further facts about the decomposition of wood by white rot fungi, as there is still sometimes maintained that white rot fungi primarily decompose the lignin and leave cellulose intact to a great extent.

As early as 1922 it was shown that the relative proportions between the wood components of oak wood attacked by the white rot fungus *Fomes igniarius* to a loss in weight of 74 per cent were not different from the proportions in the sound wood. Consequently, *F. igniarius* causes a white rot by which cellulose as well as lignin is decomposed (15).

Polyporus versicolor, also a very common storage-rot fungus on hardwoods, has proved not to change the relative proportions of wood components in the course of decay, and in this case, too, the cellulose is decomposed at about the same rate as the lignin and the pentosans (28). For the same fungus Cowling showed in 1961 (12) that, for the lignin, the total amount of carbohydrates, and also the amount of each particular sugar polymer, the rate of decomposition was practically constant at all stages of decay. He further showed that this rate of decomposition was so nearly proportional to the amounts in the original, undecayed wood that the relative proportions of these wood constituents in the rotted wood showed only a very slight difference from those of sound wood.

Thus it is obvious that the so-called white rots can decompose the cellulose and lignin as well as the corosive rots and at practically the same rate. Further it may be accepted that the white colour of wood decayed by white rot fungi cannot be the result of lignin being decomposed and cellulose being left, but rather a consequence of certain colour components being degraded (28).

IV. Moisture in sound and decayed parts of the wood

The spread of decay was marked on the discs marked *c* in Fig. 3; i.e. the parts of the wood that had been discoloured as a result of the attack by wood-rotting fungi. Test pieces were taken partly from the rotted parts and partly

from the sound—not discoloured—wood. By weighing the test pieces moist and oven-dry respectively, the moisture content was determined as percentage of weight of the absolutely dry wood (22). Density determinations were made according to the method described by Nylinder in 1953 (23).

The only explicit conclusion that could be drawn from moisture content values for decayed and undecayed parts of the wood was that moisture contents were lower in the decayed areas. However, the differences in moisture content were greater in pine and spruce than in birch wood, probably as a result of moisture contents beeing lower in birch wood than in pine and spruce.

The decrease in density was already measurable in the incipient stages of decay, when only a slight discoloration of the wood was perceptible. Examples of how the test pieces were taken and of the differences in density and moisture content between sound and decayed parts are given in Fig. 10.

Nylinder and Rennerfelt showed in 1954 (24) that the density of decayed pine and spruce was lower than that of sound wood. The differences were comparatively small, however, though the rotted volume took up a considerable part of the total volume of the wood. If, however, as has been done in this investigation, the densities of sound and decayed parts of the same piece of wood are compared, it will be seen that the differences can be considerable. As the entire wood volume rapidly rotted through, these comparisons between sound and decayed wood could not continue after the density of whole discs had decreased to 25—30 per cent of that of sound discs.

As the porosity increases in the course of decay, it is quite logical that the densities were lower in decayed parts than in undecayed parts of the wood. On the other hand it is somewhat surprising that the moisture content in rotted parts of the wood was lower than in surrounding sound parts. In laboratory experiments the moisture content in the wood has been found to increase steadily with the degree of decay. This is due to the water desorption of the fungi during the respiration. A large number of investigations of the hygroscopicity of decayed wood have been made, giving somewhat diverging results. For example Cowling showed in 1961 (12) that when the sapwood of *Liquidambar styraciflua* L. is attacked by the typical brown rot fungus *Poria monticola* Murr., the water absorption at relative humidities between 30 and 97 per cent decreased gradually along with an increased degree of decay. Moreover, Nylinder and Rennerfelt showed in 1954 (24) that the water absorption at a relative humidity of 100 per cent was higher in pine sapwood and sawdust of spruce attacked by the brown rot fungus *Lentinus lepideus* and the corrosive rot fungus *Stereum sanguinolentum* than in sound sapwood and sawdust. However, the water absorption at a humidity of 90.6 per cent was lower in rotted than in sound wood. Cowling (12) also demonstrated that in white-rotted wood no great differences existed in hygroscopical water absorption, when the wood was

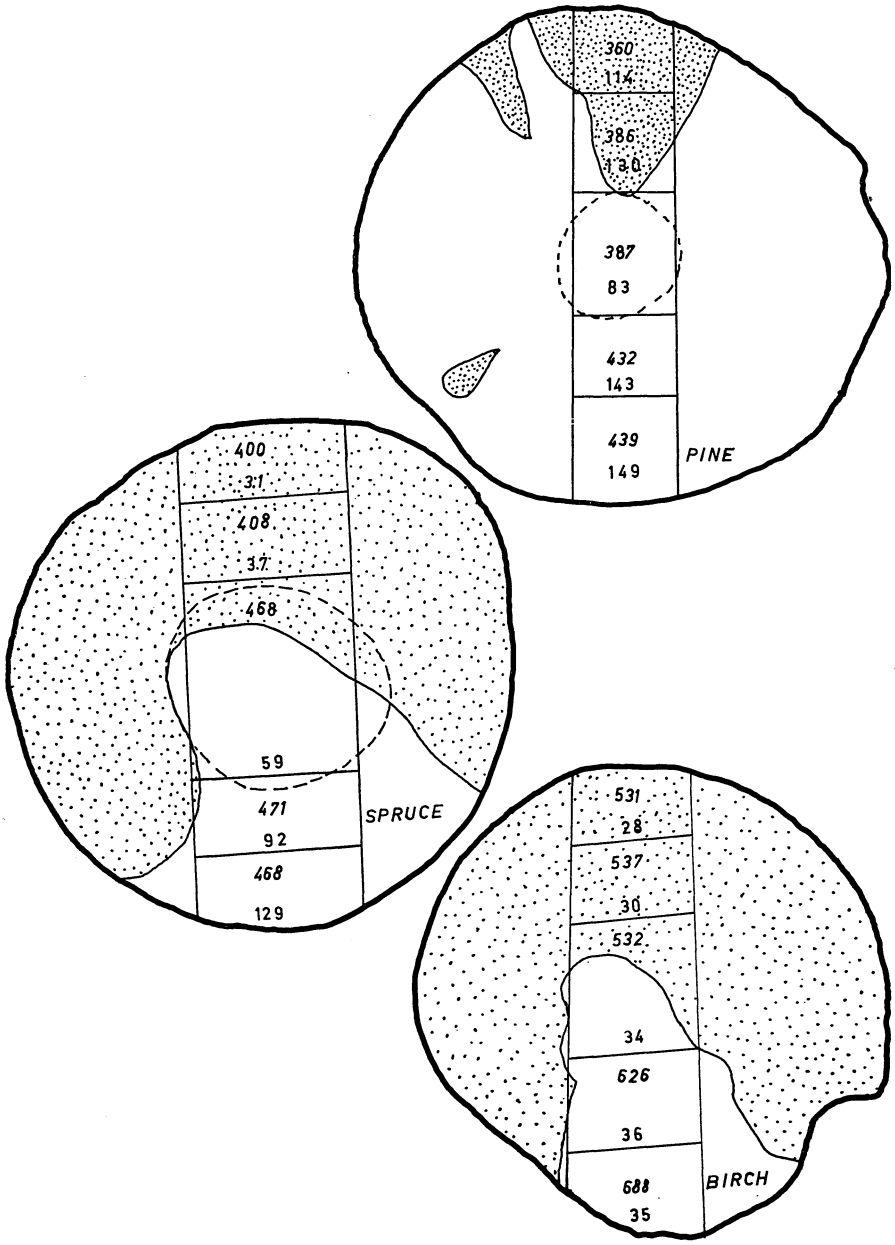


Fig. 10. Showing how the test pieces were taken for determining the densities and moisture contents in sound and decayed parts of the wood. Dotted area was discoloured by rot. Broken line shows the approximate limit of the heartwood. The upper figures show the densities of the test pieces in mg/cm³, and the lower figures show the moisture content in per cent of weight of the dry wood.

attacked by *Polyporus versicolor* to losses in weight of up to 40 per cent. However, at greater weight losses there was an obvious increase in water absorption.

In this connection, however, the hygroscopical water loss of rotted wood is of greater interest. As the original material in this experiment consisted of sound, newly-cut wood with high moisture content (100 per cent or even more), which was submitted to constant conditions in temperature and humidity, a hygroscopical water desorption must have taken place and continued until a balance had been reached between the moisture content of the wood and the humidity of the air.

Sheffer showed in 1936 (28) that wood deteriorated by the white rot fungus *Polyporus versicolor*, showed a higher water absorption as well as a higher water desorption in all cases. According to Nylinder and Rennerfelt (24) the water desorption of spruce sawdust decayed by *Lentinus lepideus* was also greater than that of sawdust from sound wood.

If the same is true for the rotted wood in this experiment, the result should thus be a lower moisture content in the decayed parts than in the sound areas, as long as the amount of respiration water, which the fungus produces, does not rise above the water amount lost from the wood under hygroscopical water desorption.

V. Matter losses and changes in density

In sound, undecayed discs the average of the densities was 0.47 ± 0.05 g/cm^3 for pine, 0.49 ± 0.05 g/cm^3 for spruce, and 0.63 ± 0.03 g/cm^3 for birch. In relation to what is considered to be the average for Swedish wood, the value for pine in this experiment is somewhat lower and for spruce and birch a little higher (19, 33).

The changes in density arising in the course of decay may be studied by comparing the values for the decayed *b*- and *e*-discs with those for the undecayed discs numbers *2* or *5* (Fig. 1 and 3). A measure of the weight losses after varying time of decay could then be obtained by expressing the densities of the decayed discs as percentage of the densities of the corresponding undecayed wiscs. The results can be seen in Table 2 and Fig. 11. It appears that the birch dood was the least resistant to attacks by wood-destroying micro-organisms, and that an attack was immediately reflected in a substantial matter loss. Spruce was the most resistant and even after 5 months no measurable weight losses had arisen. Pine takes an intermediate position, though the pine heartwood was not attacked by wood-rotting organisms until substantial time had passed. It is known that pine heartwood is more resistant to decay than pine sapwood, which is partly due to its lower water content and partly due to its content of pinosylvin phenols (26).

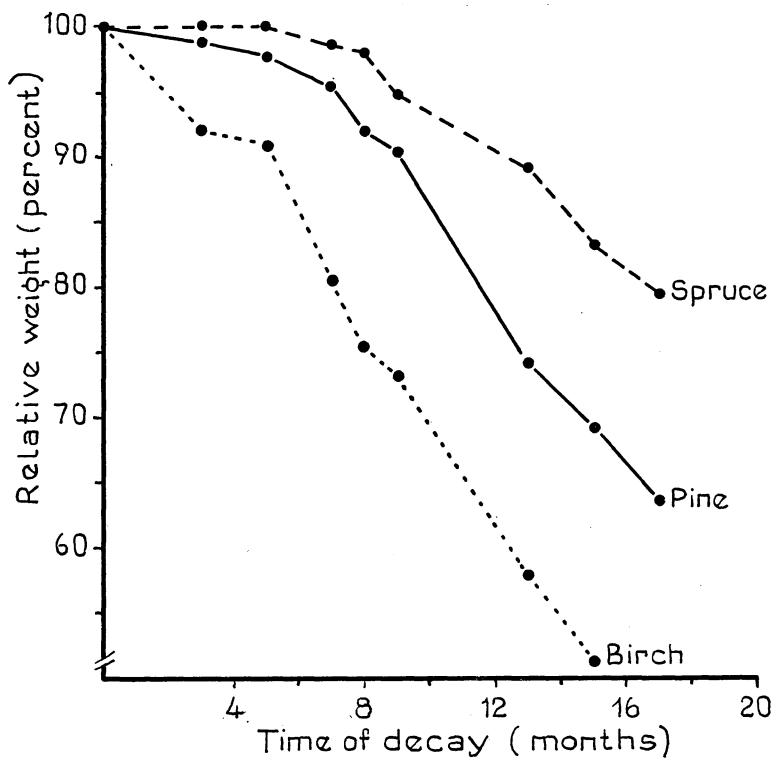


Fig. 11. Changes in relative weight during the course of decay.

Table 2. Changes in relative weight during the course of decay. The relative weight are determined as the density of decayed wood in per cent of that of sound wood

Wood species	Relative weight in per cent after various time of decay (months)								
	0	3	5	7	8	9	13	15	17
Pine	100.0	98.7	97.7	95.2	91.9	90.2	74.1	69.3	63.5
Spruce	100.0	100.0	100.0	98.6	98.0	94.7	89.0	83.1	79.5
Birch	100.0	92.0	90.8	80.5	75.4	73.2	57.9	51.2	

In his laboratory experiments, Björkman (2) could not establish any general differences between pine sapwood and spruce as to their susceptibility to decay. However, Björkman shows in later practical experiments that damage caused by blue stain and storage rot was more severe in pine timber than in spruce timber (4, 5). Steen arrived at the same result in an investigation of

deterioration of undebarked timber under storage (29). In this material too it is, as shown in Fig. 11, apparent that undebarked spruce wood showed a greater resistance than undebarked pine wood to attack by wood-destroying micro-organisms.

VI. The decomposition of the wood components

A number of *b*- and *e*-discs of determined density, representing varying weight losses, were selected from each species of wood. From each such disc a disc was cut having a thickness of about 1 cm, which was then ground in a Whiley mill with a 2 mm sieve.

These samples of ground wood were chemically analyzed for content of resins and fat, lignin, and pentosans. The analyses have kindly been performed at the Swedish Forest Products Research Laboratory. The amount of resins and fats was determined by extraction with dichloromethane and alcohol according to a method described in Technical Information CCA 2 from the Swedish Association of Pulp and Paper Engeneers (30). The lignin content was determined according to method CCA 5 employing hydrolysis against 72 per cent sulphuric acid (31), and the content of pentosans by destillation with hydrochloric acid followed by colorimetric determination with orcinol according to CCA 24: 57 (32). The amount of cellulose was then theoretically determined as the remainder. This remainder, however, also includes other polyhexoses, such as mannans and galactans, and small amounts of mineral constituents in addition to the true cellulose. This means that the cellulose contents reported here are a little to high.

The average of the percentage distribution of the wood components in the sound wood of the three wood species described in this investigation is as follows:

	Resins and Fats	Lignin	Pentosans	Cellulose
Pine	1.5 ± 0.1	28.1 ± 0.2	9.4 ± 0.3	61.0 ± 0.4
Spruce	0.8 ± 0.0	27.1 ± 0.1	8.5 ± 0.1	63.6 ± 0.2
Birch	1.4 ± 0.0	19.6 ± 0.2	27.2 ± 0.3	52.4 ± 0.4

The results of the analyses are shown in Tables 3, 4, and 5. Here can be seen the contents of cellulose, lignin, pentosans, and the dichloromethan-alcohol extracts in the sound and decayed woods. The contents are determined relative to the weight of the sound wood and the decayed wood respectively.

Table 3. The amounts of cellulose, lignin, pentosans, and dichloromethan-alcohol extract present in pine pulpwood at various stages of decay and in corresponding sound wood

Weight loss %	Amount present							
	cellulose %		lignin %		pentosans %		extract %	
	sound wood	decayed wood	sound wood	decayed wood	sound wood	decayed wood	sound wood	decayed wood
1.1	59.7	62.0	28.6	27.1	10.2	9.8	1.5	1.1
3.7	59.7	60.2	28.6	28.8	10.2	9.2	1.5	1.8
4.6	60.4	62.3	28.3	28.1	8.9	8.4	2.5	1.2
5.6	62.6	62.9	28.1	27.4	8.1	7.8	1.2	1.9
8.8	60.4	62.8	28.3	27.7	8.9	8.5	2.5	1.0
12.7	60.5	62.4	28.6	28.0	9.5	8.7	1.5	0.9
13.2	60.5	61.7	28.6	27.9	9.5	9.6	1.5	0.9
14.7	64.9	65.3	26.1	25.8	7.2	7.2	1,8	1.7
17.2	64.9	64.4	26.1	26.7	7.2	7.3	1.8	1.6
19.2	61.0	62.6	28.5	27.3	9.5	9.6	1.0	0.5
23.7	60.7	61.1	28.3	28.0	9.9	9.6	1.1	1.3
29.5	59.7	62.3	28.6	28.2	10.2	8.7	1.5	0.9
35.6	61.0	62.9	28.5	27.1	9.5	9.4	1.0	0.6
43.2	60.7	60.2	28.3	30.0	9.9	8.7	1.1	1.1
48.7	60.1	62.2	28.4	28.1	10.6	8,4	1.0	1.3
48.9	60.1	62.7	28.4	27.6	10.6	7.5	1.0	2.2

Table 3 shows that the percentage of cellulose and lignin in pine wood was not substantially changed during the course of decay. This means that they were decomposed at a rate approximately proportional to the percentage of these components in the sound wood. The percentage of pentosans, however, was generally somewhat lower in the decayed wood than in the sound wood.

Table 4. The amounts of cellulose, lignin, pentosans, and dichloromethan-alcohol extract present in spruce pulpwood at various stages of decay and in the corresponding sound wood

Weight loss %	Amount present							
	cellulose %		lignin %		pentosans %		extract %	
	sound wood	decayed wood	sound wood	decayed wood	sound wood	decayed wood	sound wood	decayed wood
1.1	62.6	61.8	27.5	28.6	9.2	8.8	0.7	0.9
1.5	63.8	63.7	27.2	27.2	8.1	8.3	0.9	0.9
2.3	63.6	63.0	26.8	27.1	8.7	8.7	0.8	1.2
3.5	64.4	64.9	27.0	26.9	7.9	7.6	0.7	0.7
7.1	63.5	62.7	26.9	27.4	9.1	9.2	0.6	0.7
8.9	64.4	63.3	27.0	28.8	7.9	7.2	0.7	0.8
12.7	63.1	63.1	27.5	28.7	8.5	7.2	0.9	0.9
14.7	62.3	63.6	28.4	27.2	8.5	8.1	0.9	1.0
19.0	65.3	60.6	26.2	32.1	8.1	6.7	0.5	0.6
20.0	63.6	58.6	27.3	33.2	8.2	7.4	0.9	0.9
25.3	64.0	61.7	26.5	29.6	8.6	7.9	0.9	0.7
31.9	63.3	64.0	27.0	27.7	8.7	7.5	1.0	0.7
34.6	63.8	55.0	26.6	36.5	9.0	7.5	0.6	1.0

Thus the pentosan content was 7.5 per cent at a loss in weight of 48.9 per cent, whereas the corresponding sound wood contained 10.6 per cent pentosans. The percentage extract varied but did not rise above 2.5 per cent in the sound wood and 2.2 per cent in the decayed wood. The low extract percentage in all samples is probably due to the loss of some volatile matter while the discs were dried for density determination.

As shown in Table 4, the lignin percentage of rotted spruce wood was usually higher and the percentage of pentosans and cellulose usually a little lower than in sound wood. This indicates that lignin was decomposed at a slower rate than the cellulose and pentosans, and also that the advance of decay here was more closely related to brown rot than in the pine wood, with an accompanying accumulation of lignin in the decayed wood. Thus the lignin percentage at a loss in weight of 34.6 per cent was as high as 36.5 per cent compared to 26.6 per cent in the sound wood. The extract percentages in the sound spruce wood varied between 0.5 and 1.0 per cent and between 0.6 and 1.2 per cent in the decayed wood.

Table 5 shows that rotted birch wood with losses in weight of up to 33 per cent had about the same percentage of wood components as the sound wood. Wood with greater losses in weight than 33 per cent were characterized by a considerably higher percentage of lignin and a substantially lower percentage of pentosans than the sound wood. At a weight loss of 68 per cent for example,

Table 5. The amounts of cellulose, lignin, pentosans, and dichloromethan-alcohol extract present in birch pulpwood at various stages of decay and in the corresponding sound wood

Weight loss %	Amount present							
	cellulose %		lignin %		pentosans %		extract %	
	sound wood	decayed wood	sound wood	decayed wood	sound wood	decayed wood	sound wood	decayed wood
5.8	52.8	54.0	19.2	19.7	26.7	25.3	1.3	1.0
12.6	50.9	52.1	19.7	19.1	28.3	27.6	1.1	1.2
13.1	53.0	52.1	19.1	19.7	26.4	27.2	1.5	1.0
19.3	53.0	51.5	19.1	20.0	26.4	27.3	1.5	1.2
22.9	50.9	50.0	19.7	22.5	28.3	26.4	1.1	1.2
23.7	52.9	55.5	18.2	17.4	27.9	26.2	1.0	0.9
23.7	52.9	55.2	18.2	17.9	27.9	25.7	1.0	1.2
25.8	52.8	52.3	19.2	23.2	26.7	23.2	1.3	1.3
25.8	54.0	54.5	19.1	18.6	25.7	25.3	1.3	1.6
32.8	52.2	55.6	18.4	17.2	27.8	26.2	1.6	1.0
32.9	50.7	55.5	19.6	18.0	28.2	25.3	1.5	1.2
40.6	48.0	49.1	21.1	27.9	29.2	21.1	1.7	1.9
45.3	52.8	55.4	19.8	27.0	26.2	16.5	1.2	1.1
51.4	53.6	54.0	19.4	23.9	25.6	20.4	1.5	1.8
58.9	52.2	54.9	19.4	24.6	26.5	19.0	1.9	1.5
68.3	52.2	48.7	19.4	31.0	26.5	17.8	1.9	2.6

the lignin content was 31.0 per cent and the pentosan content 17.8 per cent, whereas the corresponding values in the sound wood were 19.4 per cent and 26.5 per cent respectively. The extract percentage in sound birch wood varied between 1.0 and 1.9 per cent and in decayed birch wood between 0.9 and 2.6 per cent.

In Tables 6, 7, and 8, and in Fig. 12, 13, and 14 the percentage values at varying weight losses are shown of cellulose, lignin, pentosans, and dichloromethan-alcohol extract determined on the weight of sound wood. Here the rapid decomposition of cellulose in all three species of wood is clearly seen. It is further seen that the rate of decomposition of the three main components cellulose, lignin and pentosans was frequently constant, as indicated by the linearity of the decomposition curves. However, the rate of break down of cellulose in pine was apparently lower in the incipient stages of decay than in the later stages. Above about 10 per cent weight loss the rate was constant. The decomposition of lignin in birch was also non-linear and the rate of decomposition decreased a little with increasing weight loss.

In spruce the decomposition of pentosans proceeded, as shown in Fig. 13, at about the same rate as in pine whereas the decomposition of lignin was slower and the decomposition of cellulose more rapid than with the pine.

With the birch wood there was a rapid consumption of pentosans while the lignin decomposition was considerably slower, with a similar to the spruce. The extract percentage in the birch wood showed a gradual decrease at increasing weight losses.

Table 6. The amounts of cellulose, lignin, pentosans, and dichloromethan-alcohol extract present in pine pulpwood at various stages of decay. The amounts are based on weight of original sound wood

Weight loss %	Amount present based on weight of sound wood			
	cellulose %	lignin %	pentosans %	extract %
0.0	61.0	28.1	9.4	1.5
1.1	62.5	26.4	8.9	1.1
3.7	59.2	27.3	8.1	1.8
4.6	60.0	26.6	8.4	0.7
5.6	57.8	25.8	8.6	2.3
8.8	57.9	25.0	8.2	0.5
12.7	55.0	24.0	7.5	0.8
13.2	54.0	23.8	8.2	0.8
14.7	52.4	23.7	8.0	1.2
17.2	50.1	23.8	7.9	1.1
19.2	50.6	21.7	7.7	0.6
23.7	46.8	21.2	6.9	1.3
29.5	44.8	19.5	5.6	0.7
35.6	40.5	17.2	6.0	0.6
43.2	34.3	16.9	4.7	0.8
48.7	32.4	14.3	3.8	1.0
48.9	31.9	14.0	3.4	1.8

Table 7. The amounts of cellulose, lignin, pentosans, and dichloromethan-alcohol extract present in spruce pulpwood at various stages of decay. The amounts are based on weight of original sound wood

Weight loss %	Amount present based on weight of sound wood			
	cellulsoe %	lignin %	pentosans %	extract %
0.0	63.6	27.1	8.5	0.8
1.1	62.0	27.8	8.0	1.1
1.5	62.5	26.7	8.5	0.7
2.3	61.6	26.7	8.3	1.2
3.5	61.9	26.0	7.9	0.6
7.1	58.4	25.7	8.0	0.9
8.9	56.9	26.3	7.0	0.6
12.7	55.5	24.7	6.3	0.7
14.7	55.5	22.1	7.0	0.8
19.0	47.8	26.9	5.7	0.8
20.0	46.9	26.4	6.1	0.7
25.3	45.9	22.6	5.9	0.5
31.9	43.8	18.9	5.0	0.6
34.6	35.7	24.3	4.6	0.9

Table 8. The amounts of cellulose, lignin, pentosans, and dichloromethan-alcohol extract present in birch pulpwood at various stages of decay. The amounts are based on weight of original sound wood

Weight loss %	Amount present based on weight of sound wood			
	cellulose %	lignin %	pentosans %	extract %
0.0	52.4	19.1	27.2	1.4
5.8	50.5	18.4	24.3	1.0
12.6	46.9	16.2	23.2	1.3
13.1	44.7	17.1	24.3	0.9
19.3	41.1	16.1	22.4	0.9
22.9	39.6	16.8	19.6	1.2
23.7	41.9	13.9	19.5	1.0
23.7	41.7	14.3	19.2	1.3
25.8	38.5	17.1	17.5	1.0
25.8	39.4	13.8	19.9	1.3
32.8	37.5	12.0	17.2	0.6
32.9	38.4	11.8	16.4	0.7
40.6	31.8	15.2	11.7	0.9
45.3	30.0	14.3	9.4	0.7
51.4	25.7	11.4	10.5	0.8
58.9	22.6	10.0	8.0	0.4
68.3	15.5	9.7	5.8	0.6

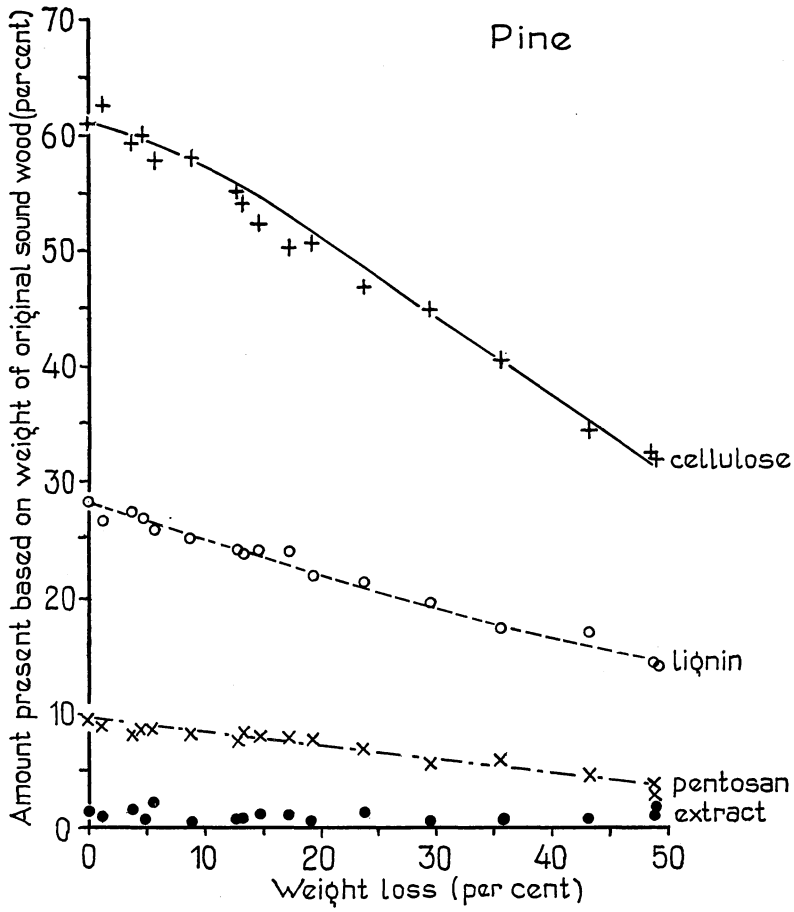


Fig. 12. Composition of pine pulpwood at various stages of decay. The amounts are based on weight of original sound wood.

In Table 9 are shown the losses of wood components at varying weight losses, expressed as per cent of the original amounts. The loss of cellulose in the three species of wood and the loss of lignin in pine was generally in agreement with the total weight loss. The lignin decomposition in spruce and birch proceeded at a lower rate than the total decomposition (weight loss), so that, for example, at a loss in weight of about 25 per cent only 16.8 and 19.0 per cent respectively of the original lignin had been decomposed. Finally, in the three species of wood the decomposition of pentosans proceeded at a higher rate than the total decomposition. For instance in birch wood at a loss in weight of 68.3 per cent, 78.7 per cent of the original amount of pentosans had been consumed.

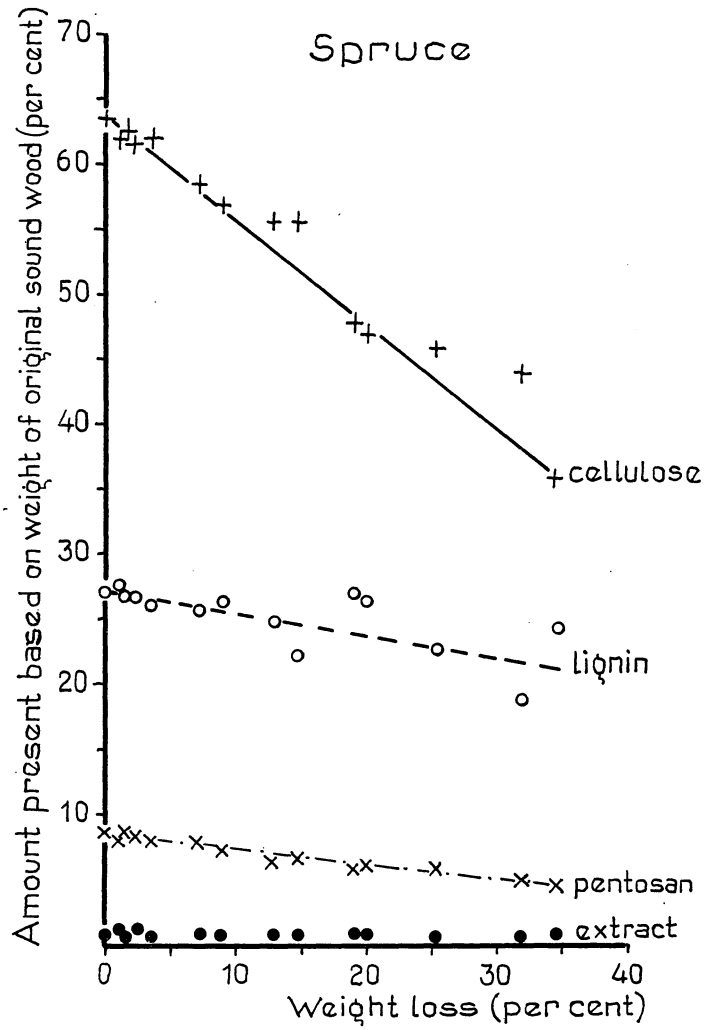


Fig. 13. Composition of spruce pulpwood at various stages of decay. The amounts are based on weight of original sound wood.

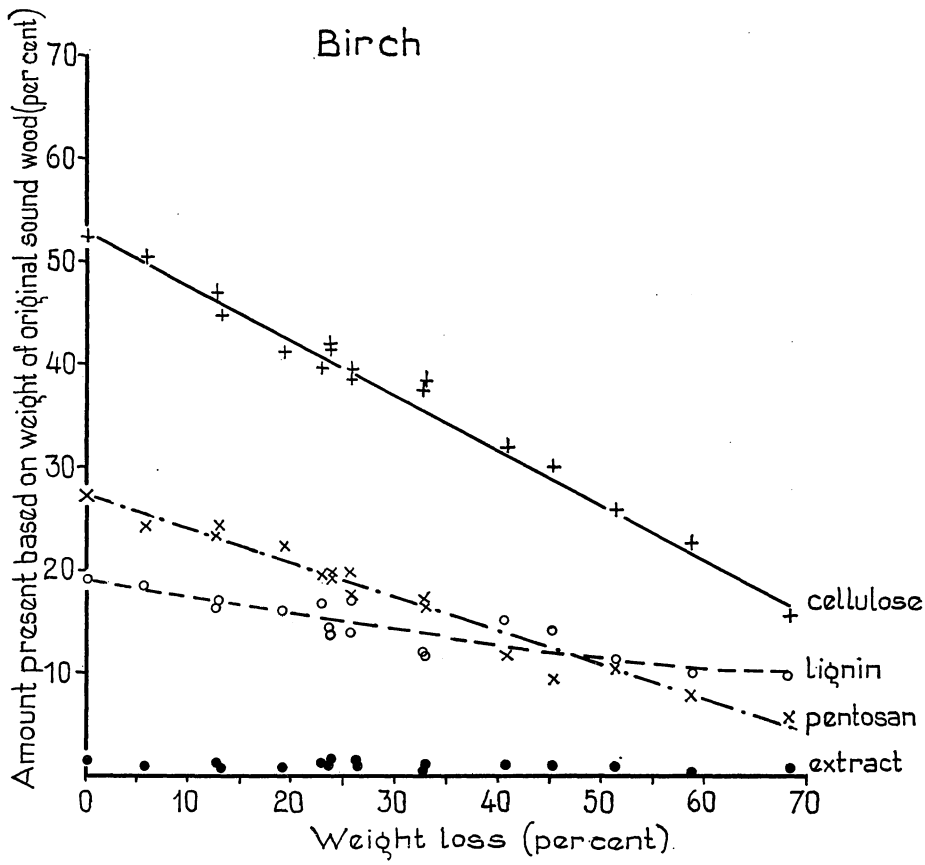


Fig. 14. Composition of birch pulpwood at various stages of decay. The amounts are based on weight of original sound wood.

Considering the flora of wood-rotting fungi in the test material, the results of the wood analyses are generally what one expects. In the pine and spruce woods fungi causing a more or less typical corrosive rot were the most frequent, with consequent decomposition of the cellulose as well as the lignin of the wood. This conclusion is supported by this investigation. In many previous investigations (8, 9, 10, 12, 28) various white rot fungi have been shown to have the power of decomposing lignin as well as cellulose. In this investigation mostly white rot fungi occurred in the birch wood, and here cellulose as well as lignin had been decomposed in accordance with the preceding statement.

Of particular interest is the fact that in all three species of wood an approxi-

Table 9. Loss of the wood components (in per cent of the original amounts of these constituents) at various weight losses. × = average of analyses from two test samples

Weight loss %	Loss of wood components								
	cellulose %			lignin %			pentosans %		
	pine	spruce	birch	pine	spruce	birch	pine	spruce	birch
1.1	0.0	2.5		6.1	0.0		5.4	5.3	
1.5		1.7			1.5			0.0	
2.3		3.2			1.3			1.9	
3.5		2.6			4.1			7.3	
3.7	2.9			2.8			13.6		
4.6	1.6			5.5			9.4		
5.6	5.2			8.1			8.7		
5.8			3.6			3.6			10.7
7.1		8.2			5.3			5.8	
8.8	5.1			10.9			12.5		
8.9		10.5			2.9			17.5	
12.6			10.5			15.2			14.7
12.7	9.9	12.7		14.5	9.0		20.2	26.0	
13.1			14.7			10.5			10.5
13.2	11.5			15.3			12.3		
14.7	14.1	12.8		15.7	18.3		14.8	18.0	
17.2	17.9			15.3			15.9		
19.0		24.8			0.6			32.4	
19.2	17.1			22.6			18.6		
19.3			21.6			15.8			16.5
20.0		26.2			2.7			28.2	
22.9			24.4			11.9			28.1
23.7	23.2		20.2 ×	24.4		26.0 ×	26.4		29.0 ×
25.3		27.9			16.6			30.8	
25.8			25.7 ×			19.0 ×			31.2 ×
29.5	26.6			30.6			40.5		
31.9		31.1			30.1			41.0	
32.2			28.5			37.2			36.6
32.9			26.7			38.2			39.9
34.6		43.7			10.1			46.0	
35.6	33.6			38.9			36.0		
40.6			39.2			20.5			57.0
43.2	43.7			39.7			50.3		
45.3			42.7			25.4			65.6
48.7	46.9			49.2			59.1		
48.9	47.7			50.3			63.9		
51.4			51.0			40.2			61.3
58.9			56.8			47.8			70.6
68.3			70.4			49.3			78.7

mately corresponding amount of cellulose was consumed at a particular weight loss in the decayed wood. This indicates that knowing the weight loss in decayed wood, one has a rough measure of the cellulose loss, provided that the decay is mainly of the corrosive or white rot nature.

Summary

The biological deterioration of pulpwood from *Pinus silvestris*, *Picea abies*, and *Betula pubescens* has been investigated in a model experiment. Undebarked samples of these species were placed without preceding sterilization, under conditions favourable to the development of wood-destroying organisms (temperature 20—22° C, relative humidity 98—99 per cent). During the experiment the rot fungus flora in the wood were continously studied, in addition to the moisture conditions in sound and decayed parts of the wood, losses in wood substance, and the decomposition of the wood components cellulose, lignin, and pentosans.

The test wood generally became infected from the end surfaces but also from branch wounds and other injuries to the bark. With birch the decay in a cross-section could initially be seen as small stains lighter than the surrounding sound wood. However, in the coniferous wood the decay appeared at first as yellowish, brownish, or reddish sectors and stains in the sapwood.

The rot fungus flora in the wood are listed in Table 1. They are closely similar in pine and spruce and consisted mainly of corrosive rot fungi with the power to decompose lignin as well as the cellulose of the wood. The most common and first appearing wood-rotting fungus in the coniferous wood was *Peniophora gigantea*. In birch, however, white rot fungi occurred mostly. These also decompose both the lignin and the cellulose of the wood. The most common wood-rotting fungi in birch were *Polyporus zonatus* and *Lenzites betulina*.

The densities were lower in the decayed than in the sound parts of the wood. The moisture content was also lower in decayed than in sound wood irrespective of the particular species of wood.

In all three species of wood studied the densities decreased during the experiment as shown in Fig. 11, and considerable weight losses to the birch occurred, after only a few months. Spruce was the most resistant to attacks by decay and after 5 months no weight loss in the wood could be registered.

By analyses of the sound and decayed woods it was ascertained that cellulose as well as lignin and pentosans was decomposed in the course of decay, which can be seen in Fig. 12, 13, and 14. In pine wood the decomposition of these components took place roughly in proportion to their occurrence in the sound wood. In spruce and birch lignin decomposition was slower than in pine. In the three species of wood the loss of cellulose was almost directly correlated to the total weight loss, so that for a particular percentage weight loss in the wood there was a corresponding loss of cellulose. The decomposition of pentosans proceeded at a higher rate than the total loss of matter, so that for a particular percentage weight loss in the wood, there was a greater percentage loss of pentosans.

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Sammanfattning

Studier över rötsvampars nedbrytning av tall-, gran- och björkmassaved

I ett modellförsök har den biologiska nedbrytningen av massaved av *Pinus silvestris*, *Picea abies* och *Betula pubescens* studerats. Obarkade bitar av dessa träslag placerades utan föregående sterilisering under för vedförstörande organismers utveckling så gynnsamma förhållanden som möjligt (20—22° C temperatur och 98—99 % relativ luftfuktighet). Under försökstidens gång studerades fortlöpande svampfloran i veden, fuktförhållandena i frisk och rötad ved, förluster av vedsubstans samt nedbrytningen av vedbeståndsdelarna cellulosa, lignin och pentosan.

Försöksvirket hade oftast infekterats från ändytorna men även via kvistsår och andra barkskador. Hos björkvirket kunde rötan på ett tvärsnitt först urskiljas som små fläckar, ljusare än omgivande frisk ved. Hos barrveden däremot uppträdde rötan först som gul- brun- eller rödaktiga sektorer och fläckar i splintveden.

Rötsvampfloran i veden demonstreras i Tab. 1. Därav framgår, att den hos tall och gran var ungefär densamma och främst utgjordes av korrosionsrötesvampar med förmåga att nedbryta såväl vedens lignin som cellulosa. Den allmännaste och tidigast uppträdande rötsvampen i barrveden var *Peniophora gigantea*. I björkveden förekommo däremot mest vitrötesvampar. Även dessa nedbryta vedens lignin och cellulosa. De allmännaste rötsvamparna i björkveden voro *Polyporus zonatus* och *Lenzites betulina*.

Volymvikterna voro lägre i rötade än i friska partier av veden. Även fuktkvoterna voro lägre i rötad än i frisk ved oberoende av träslag.

Hos alla tre träslagen sänktes torrvolymvikterna under försökets gång, vilket visas av Fig. 11, och avsevärda viktsförluster orsakades på björkveden redan efter några månader. Granveden var mest resistent mot rötangrepp, och ännu efter 5 månader kunde inte några viktsförluster hos veden registreras.

Genom analyser av den friska och rötade veden kunde konstateras, att såväl cellulosan som ligninet och pentosanerna nedbrötos under rötförloppet, vilket kan ses i Fig. 12, 13 och 14. Hos tallveden skedde nedbrytningen av dessa beståndsdelar ungefär i proportion till deras förekomst i den friska veden. Hos gran- och björkveden skedde ligninnedbrytningen långsammare än hos tallveden. Hos alla tre träslagen var förlusten av cellulosa nära nog direkt korrelerad med den totala viktsförlusten, så att vid en viss procentuell viktsförlust hade en motsvarande procentuell förlust av cellulosa ägt rum. Pentosannedbrytningen fortgick med större hastighet än den totala substansförlusten, så att vid en viss procentuell viktsförlust hos veden hade en större procentuell för lust av pentosan ägt rum.