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# Microbial decomposition of unpeeled birch and aspen pulpwood during storage

*Mikrobiell nedbrytning av obarkad björk- och asp-massaved under lagring*

by

BJÖRN HENNINGSSON

SKOGSHÖGSKOLAN

STOCKHOLM

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# I. Introduction

The present study is part of a comprehensive investigation concerning microbial attack on pulpwood of birch and aspen. The climate of storage places, the fungus flora, and the changes in moisture content, dry density and chemical composition of the stored wood will be described and discussed. Changes in pulp yield, pulp quality, strength of the wood, etc., will be reported in further papers.

The damage caused to pulpwood by micro-organisms has usually been reported in terms of a decrease in pulp yield as compared to the yield from sound wood. This decrease mainly reflects the lower quality of the decayed wood. During storage, however, there is a loss of cellulose, caused by the more or less complete microbial decomposition and metabolism of this substance. This loss is not apparent in pulp yield measurements unless the losses of wood substance and the changes in chemical composition during storage are known. One of the main objects of the present paper is to describe how some of these factors may change during storage in different parts of Sweden.

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## II. Materials and methods

The experimental material was stored from May 1963 to October 1965 in five places in Sweden, viz. Ryd, Björneborg, Skinnskatteberg, Njurunda and Vuollerim (Fig. 1).

The experimental material consisted of *Populus tremula* L. and *Betula pubescens* Ehrh., except in Ryd, where the birch species was *Betula verrucosa* Ehrh.

Immediately after felling, the trees were cut into logs about 2.3 m long. In addition from each tree species 20 logs intended for pulp and chemical analysis were cut to a length of about 3.3 m. On the day of stacking (usually from two to four days after felling) the logs were cut according to the schedule in Fig. 2, and the disks representing the original wood were debarked and weighed. Each log was numbered, the dimensions and the number of branch scars being recorded. Close stacks of about 1.5 m in height, oriented in an east-west direction and containing 80 unpeeled pulpwood logs of each wood species, were built up. On each side of the stacks a protective stack about 0.5 m broad was built in order to obtain conditions as uniform as possible for the experimental material.

The disks representing the sound wood were placed in plastic bags and transported immediately to Skogshögskolan in Stockholm, where the wet and dry volume and the dry weight of the disks were measured according to a method described by PETERSON & WINQVIST (1960). The wood samples intended for pulp and chemical analysis were debarked and dried. They were then transported to Skogshögskolan and kept in a dry condition until the analyses were performed.

At intervals of three or six months, ten logs of each tree species, representing all layers of the stack, were withdrawn and cut according to Fig. 2. The disks and the wood samples intended for analysis were treated in the same way as those taken at the beginning of the experiment. From the results of weighing, the moisture contents and the dry densities were calculated.

On every sampling occasion, each log was examined for sporophores of decay fungi, in order to compare the outer appearance of the logs with the internal wood destruction. By means of an increment borer, sterilised in ethanol, cores were taken from each of the withdrawn logs.

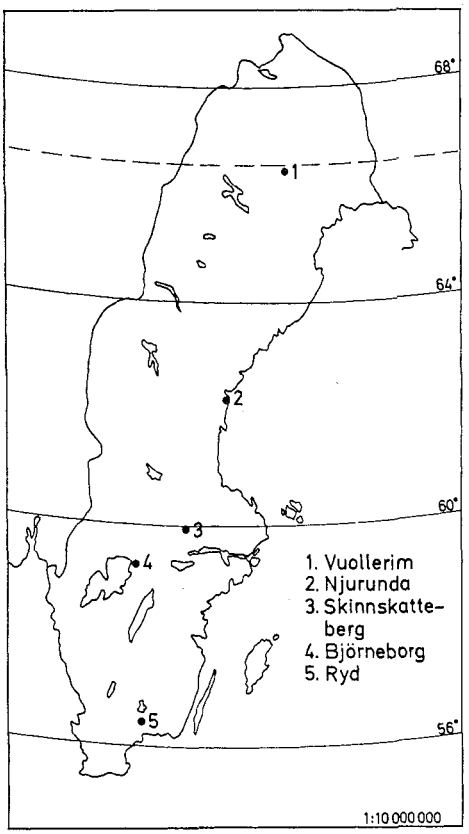


Fig. 1. Map showing the geographical location of the five storage places.

The cores were treated according to HENNINGSSON (1965), and the micro-organisms growing out were isolated. Some of the mycelia were kindly identified by Dr. A. KÄÄRIK at Skogshögskolan, Stockholm. Some of the identified fungal strains were used in physiological and other experiments (HENNINGSSON 1967).

The disks from each log intended for chemical analysis were ground up together to give one sample. A Whiley mill with a 1.5 mm sieve was used. After 1 gm wood meal and 20 ml redistilled water had been shaken together for 20—24 hours at room temperature, the pH was determined on the filtrate. The lignin analyses were performed according to a method described in Technical Information CCA2 from Swedish Association of Pulp and Paper Engineers, employing sulphuric acid hydrolysis. The cellulose content was determined by a method

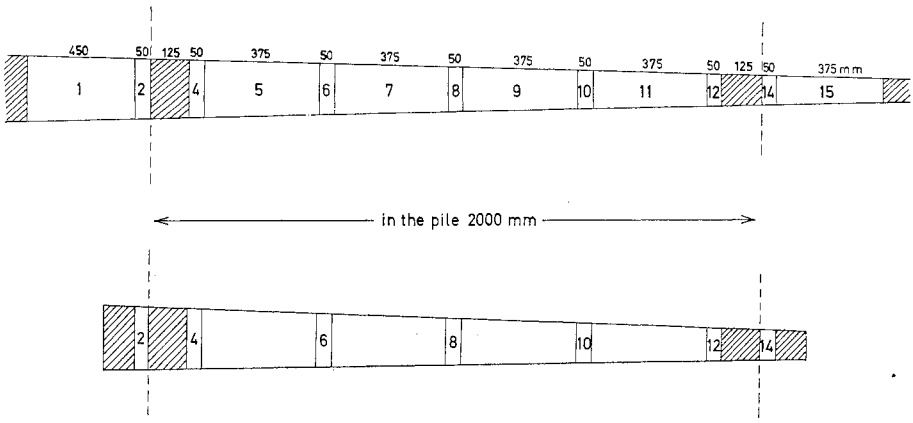


Fig. 2. Cutting schedule for the experimental material. The upper figure schematically represents a log intended for pulp and chemical analysis and the lower figure a log not intended for pulp and chemical analysis. The numbered wood samples were used as follows:
1 and 15: pulp and chemical analysis of the sound wood.
2 and 14: measurements of density and moisture content of the sound wood.
4, 6, 8, 10, and 12: measurements of density and moisture content of the stored wood.
5, 7, 9, and 11: pulp and chemical analysis of the stored wood.
Streaked parts of the wood were discarded. In order to avoid branches in the disks intended for density measurements, the positions of these sometimes had to be moved a few centimetres.

described by SEIFERT (1956). This method employs the use of acetylacetone and hydrochloric acid and gives a cellulose completely free from hemicelluloses, the yield being a few per cent lower than that of the Cross-Bevan method.

# III. Results

## A. The climates of the storage places

The climatic factors of the storage place are of great importance to the activities of the microflora which are infecting and which have already infected stored pulpwood. The development of spores and germ tubes is, for instance, affected by temperature, relative humidity and moisture of wood surface (HOPP 1938, HAYASHI 1952, KÄÄRIK 1960, MORTON & FRENCH 1966); the last factor being influenced in its turn by the precipitation. The growth and decay activity of the wood-inhabiting microbes and the interactions between them are influenced by the temperature and the moisture of the wood (cf. HUMPHREY & SIGGERS 1933, BJÖRKMAN 1946, AMMER 1964, HENNINGSSON 1967).

A comparison between the monthly average temperatures during the experimental period at the meteorological stations nearest to the five storage places is shown in Fig. 3. The underlying data have been taken from SMHI Yearbooks (Nos. 45, 46 and 47). Even if certain blue stain fungi have been shown to grow slowly at temperatures below 0° C (von PECHMANN et al. 1964), it might be convenient here to describe the microbial growing season as that period of the year during which the average daily temperature is above 0°C. It is evident from Fig. 3 that the temperatures at Karlstad (Björneborg) and Västerås (Skinnskatteberg) were greatly similar. Fig. 3 also demonstrates that the growing season in Karlshamn (Ryd) extended two to three months longer in both spring and autumn than in Jokkmokk (Vuollerim); 1.5 to 2.5 months longer than in Sundsvall (Njurunda) and 0.5 to 2 months longer than in Karlstad (Björneborg) and Västerås (Skinnskatteberg). The summer temperatures were highest in Skinnskatteberg and lowest in Vuollerim. These differences in length of growing season must have had a decisive influence on the microbial decomposition of the wood.

Fig. 4 demonstrates the daily maximum and minimum temperatures on the shade side of the pile in Ryd, recorded from May 1963 to February 1964. The daily temperature-range was higher during summer than during autumn and winter, sometimes amounting to

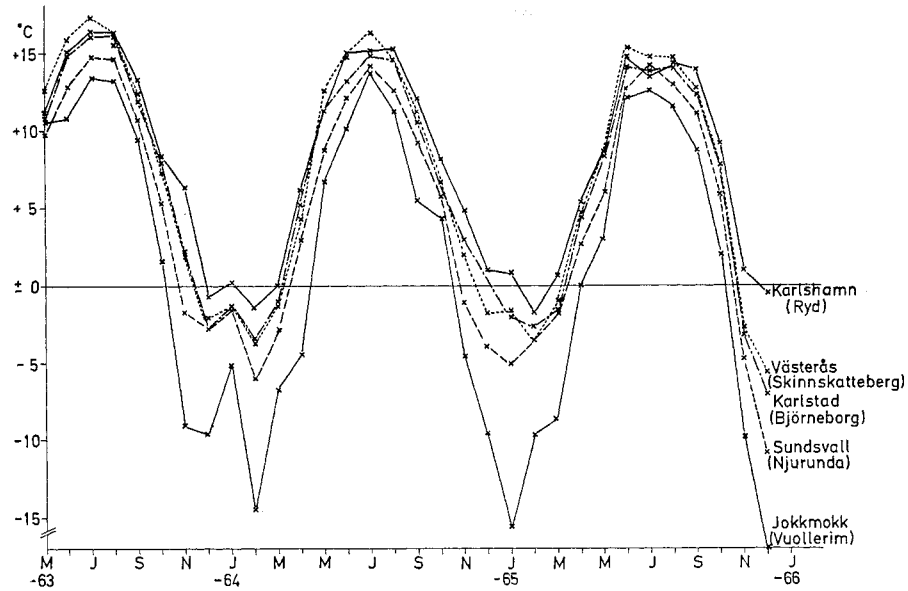


Fig. 3. Mean monthly temperatures during the experimental period at the meteorological stations nearest the five storage places.

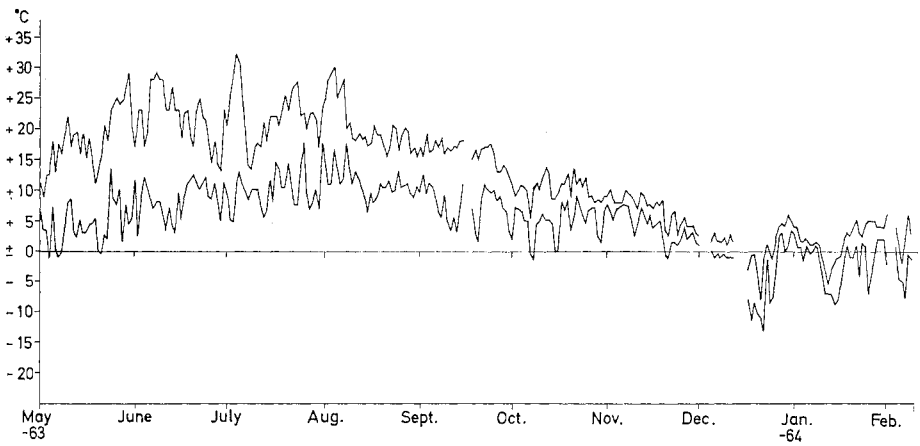


Fig. 4. Daily maximum (upper curve) and minimum (lower curve) temperatures recorded from May 1963 to Feb. 1964 on the shade (north) side of the stack in Ryd.

20—25 °C. Such a temperature-range greatly influences microbial interrelationships, e.g. the antagonism between microbes in the wood (HENNINGSSON 1967). Furthermore, the long period in autumn when the temperature was low and the variations slight might have

**Tab. 1. Monthly precipitation (mm) during the storage period at the meteorological stations nearest the five storage places.**

| Year | Month | Precipitation m. m. | | | | |
|---|---|---|---|---|---|---|
| | | Karlshamn | Karlstad | Västerås | Sundsvall | Jokkmokk |
| 1963 | M | 21 | 49 | 27 | 34 | 45 |
| | J | 58 | 39 | 73 | 61 | 41 |
| | J | 24 | 48 | 67 | 41 | 80 |
| | A | 135 | 125 | 86 | 95 | 98 |
| | S | 47 | 39 | 32 | 50 | 78 |
| | O | 70 | 104 | 60 | 70 | 28 |
| | N | 115 | 122 | 77 | 93 | 52 |
| | D | 6 | 6 | 16 | 41 | 32 |
| | Sum | 476 | 532 | 438 | 485 | 454 |
| 1964 | J | 21 | 6 | 4 | 1 | 6 |
| | F | 16 | 19 | 26 | 41 | 31 |
| | M | 3 | 4 | 0.2 | 8 | 3 |
| | A | 26 | 16 | 12 | 9 | 38 |
| | M | 32 | 34 | 64 | 29 | 37 |
| | J | 42 | 97 | 51 | 55 | 56 |
| | J | 43 | 50 | 61 | 66 | 30 |
| | A | 18 | 40 | 66 | 109 | 147 |
| | S | 35 | 58 | 69 | 101 | 36 |
| | O | 65 | 118 | 77 | 81 | 24 |
| | N | 39 | 61 | 46 | 33 | 55 |
| | D | 76 | 52 | 40 | 44 | 40 |
| | Sum | 416 | 555 | 516 | 577 | 503 |
| 1965 | J | 60 | 50 | 64 | 78 | 56 |
| | F | 21 | 7 | 23 | 31 | 35 |
| | M | 18 | 13 | 8 | 17 | 51 |
| | A | 38 | 45 | 34 | 65 | 20 |
| | M | 77 | 23 | 9 | 19 | 36 |
| | J | 46 | 60 | 60 | 30 | 54 |
| | J | 114 | 109 | 129 | 106 | 43 |
| | A | 34 | 61 | 46 | 61 | 85 |
| | S | 85 | 77 | 113 | 117 | 47 |
| | O | 10 | 13 | 13 | 19 | 61 |
| | Sum | 503 | 458 | 499 | 543 | 488 |
| Precipitation during the whole storage period | | 1,395 | 1,545 | 1,453 | 1,605 | 1,445 |

favoured the development of certain microbes, e.g. certain decay fungi at the expense of certain bacteria (HENNINGSSON 1967). It is also of importance to note that even during winter the temperature on many days was high enough to allow activity by the decay fungi.

The precipitation figures in Tab. 1 show that in 1963 Karlstad (Björneborg) was the place with the highest precipitation—mainly because of heavy rainfall in August, October and November. In 1964

Sundsvall and Karlstad received most precipitation. August was generally the month with highest precipitation during 1963 and 1964. In 1965 precipitation was highest in Sundsvall. July and September were the rainiest months in 1965 for most stations concerned. As the experimental material consisted of unpeeled pulpwood logs, it is not realistic to assign too much importance to the precipitation as regards the microbial wood decomposition itself. Its most important effect is certainly to make end surfaces and other exposed parts of the wood moist enough to allow germination of spores and growth of germ tubes—especially during the initial period of storage and during early autumn, when the amount of spores in the air is usually at its highest (cf. RENNERFELT 1947, KÄÄRIK 1955). Spores of many wood-destroying fungi require free water for germination. The fact that July, August and September were generally the rainiest months during the storage period, must thus have favoured infection.

The relative humidity influences spore germination (KÄÄRIK 1960). Measurements of relative humidity on the shade side of the pile in Ryd showed that the daily maximum relative humidity during the 1963 growing season ranged between 60 and 90 per cent. These values were reached early in the morning, when the temperature was at its lowest. At the warmest time of the day, air humidity was usually at its lowest—25 to 80 per cent. However, owing to evaporation from the logs, the humidity near the exposed wood surfaces might be expected to be higher than the general humidity. Since the daily temperature during the growing season varied considerably (Fig. 4), the formation of dew on the logs was not unusual when humidity was high.

### B. Sporophores of decay fungi on the logs

At every sampling, the sporophores of decay fungi occurring on the logs were recorded. Sporophores developed both on end surfaces and on the bark. Generally, sporophore frequency was lower on aspen than on birch, lower on the sunny (south) side than on the shade (north) side of the piles and low in Vuollerim compared with the other storage places. The sporophore records are presented in Tab. 2 a, 2 b, 2 c, 2 d and 2 e. It is evident that there was a certain sequence in sporophore development. On birch wood the *Corticium* species—mainly *Corticium laeve* Pers. but sometimes also *Corticium confluens* Fr.—developed during the first growing season. In some places *Stereum purpureum* Fr. and *Peniophora incarnata* (Pers.) Karst., too, were observed towards the end of the first, but usually did not become

**Tab. 2. Occurrence of sporophores of decay fungi on the experimental material in: a) Ryd, b) Björneborg, c) Skinnskatteberg, d) Njurunda and e) Vuollerim.**

**Explanation: single = observed on a single log; few = observed on upto 10 per cent of the logs; common = observed on 10—50 per cent of the logs; general = observed on more than 50 per cent of the logs.**

Ryd

| Date | Type of wood | Frequency of logs with sporophores of the most common decay fungi | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | *Corticium* spp. | *Stereum purpureum* | *Libertella betulina* | *Stereum hirsutum* | *Polyporus zonatus* group | *Peniophora incarnata* | |
| Oct. -63 | birch | general (covering great areas) | common | 0 | 0 | 0 | single | *Trichoderma sp.* observed. |
| May -64 | » | general (covering great areas) | common | common | 0 | single (small) | few | |
| Oct. -64 | » | general (old) | common | general | common | common | common | *Phlebia radiata*, *Stereum rugosum*, *Schizophyllum commune* and *Tremella foliacea* observed. |
| May -65 | » | general (fragments) | common (old) | few (old) | common | common | general | *Polyporus adustus*, *Lenzites betulina*, *Stereum rugosum* and *Tremella foliacea* observed. |
| Oct. -65 | » | common (fragments) | few (old) | 0 | general | common | common | *Lenzites betulina* and *Polyporus hirsutus* common in the upper parts of the stacks. *Hypoxylon multiforme*, *Panus stipticus*, *Polyporus adustus*, *Schizophyllum commune*, *Stereum rugosum* and *Tremella foliacea* observed. |
| Oct. -63 | aspen | general | common (small) | 0 | 0 | 0 | 0 | Most of the bark still alive. *Schizophyllum commune* observed. |
| May -64 | » | general | general | 0 | 0 | 0 | 0 | Areas with living bark occurring. |
| Oct. -64 | » | general (covering great areas) | general (covering great areas) | 0 | 0 | single | 0 | Logs shedding their bark. *Corticiaceae* sp., *Polyporus* sp. and *Schizophyllum commune* observed. |
| May -65 | » | general (old and new) | general (fragments) | 0 | 0 | few | few | *Polyporus hirsutus* observed in the upper parts of the stacks. |
| Oct. -65 | » | general (old and new) | common (old) | 0 | single | common | common | *Polyporus hirsutus* in the upper parts of the stacks. *Corticum* sp., *Hypoxylon concentricum*, *Myxomycetes* sp. (yellow), *Polyporus adustus* and *Schiziophyllum commune* observed. |

Björneborg

| Date | Type of wood | Frequency of logs with sporophores of the most common decay fungi | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | *Corticium* spp. | *Stereum purpureum* | *Libertella betulina* | *Stereum hirsutum* | *Polyporus zonatus group* | *Peniophora incarnata* | |
| Oct. -63 | birch | general (small) | single (small) | 0 | 0 | 0 | 0 | Areas with living bark occurring. |
| May -64 | » | general (old) | single | few | 0 | 0 | 0 | *Trichoderma* sp. common in the middle part of the stacks. |
| Oct. -64 | » | general (old) | common | common | common | few | few | *Coryne sarcoides*, *Pholiota heteroclita*, *Polyporus adustus*, *Polyporus betulinus*, *Stereum rugosum* and *Tremella foliacea* observed. |
| May -65 | » | general (old and new) | common (old) | common (old) | common | common | general | *Coryne sarcoides*, *Polyporus adustus*, *Stereum rugosum* and *Tremella foliacea* observed. |
| Oct. -65 | » | common | few (old) | 0 | general | general | general | *Polyporus adustus*, *Polyporus betulinus*, *Stereum rugosum* and *Hypoxylon multiforme* observed. |
| Oct. -63 | aspen | few (small) | 0 | 0 | 0 | 0 | 0 | Most of the bark still alive. |
| May -64 | » | few (small) | 0 | 0 | 0 | 0 | 0 | Areas with living bark common. |
| Oct. -64 | » | common | few | 0 | 0 | few | 0 | *Corticiaceae* sp. (grey) and *Myxomycetes* sp. (red) observed. |
| May -65 | » | general (old) | common (old) | 0 | 0 | few | few | *Corticiaceae* sp. (grey) observed. |
| Oct. -65 | » | general (old and new) | common (old) | 0 | 0 | common | common | *Corticiaceae* sp. (grey) and *Myxomycetes* sp. (red) observed. |

Skinnskatteberg

| Date | Type of wood | Frequency of logs with sporophores of the most common decay fungi | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | *Corticium* spp. | *Stereum purpureum* | *Libertella betulina* | *Stereum hirsutum* | *Polyporus zonatus* group | *Peniophora incarnata* | |
| Oct. -63 | birch | common | 0 | 0 | 0 | 0 | single | *Trichoderma* sp. common. |
| May -64 | » | general (old and new) | few | few | 0 | 0 | few | *Trichoderma* sp. observed. |
| Oct. -64 | » | general | few | common | common | common | common | *Corticiaceae* sp., *Coryne sarcoides*, *Polyporus adustus*, *Stereum rugosum* and *Tremella foliacea* observed. |
| May -65 | » | general (old) | few (old) | common (fragm.) | general | common | general | *Corticiaceae* sp., *Hypoxylon multiforme* and *Stereum rugosum* observed. |
| Oct. -65 | » | general (fragments) | 0 | 0 | general | common | common | *Hypoxylon multiforme*, *Hypoxylon concentricum*, *Lenzites betulina*, *Polyporus adustus*, *Stereum rugosum* and *Tremella foliacea* observed. |
| Oct. -63 | aspen | common | 0 | 0 | 0 | 0 | 0 | Most of the bark still alive. |
| May -64 | » | general (covering geat areas) | few | 0 | 0 | 0 | 0 | Areas with living bark occurring. Fruiting *Myxomycetes* sp. observed. |
| Oct. -64 | » | general (covering great areas) | general (covering great areas) | 0 | 0 | few | single | *Corticiaceae* sp. (grey-red) and *Myxomycetes* sp. (red) observed. |
| May -65 | » | general | general (old and new) | 0 | 0 | common | common | *Polyporus zonatus* found in the upper parts of the stacks only. |
| Oct. -65 | » | general | general (old) | 0 | single | common | common | *Corticiaceae* sp., *Exidia pithya*, *Polyporus adustus*, *Polyporus pubescens*, *Stereum rugosum* and *Myxomyceles* sp. (yellow) observed. |

Njurunda

| Date | Type of wood | Frequency of logs with sporophores of the most common decay fungi | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | *Corticium* spp. | *Stereum purpureum* | *Libertella betulina* | *Stereum hirsutum* | *Polyporus zonatus* group | *Peniophora incarnata* | |
| Oct. -63 | birch | common | single | 0 | 0 | 0 | 0 | Areas with living bark occurring. |
| June -64 | » | general (old and new) | 0 | few | 0 | 0 | 0 | |
| Oct. -64 | » | general (old and new) | common | common | 0 | single | common | |
| May -65 | » | general (old and new) | common | common (fragm.) | few | few | common | *Corticiaceae* sp. and *Polyporus adustus* observed. |
| Sept. -65 | » | general | common (old) | 0 | common | few | common | *Corticiaceae* sp., *Hypoxylon multiforme*, *Phlebia radiata* and *Polyporus adustus* observed. |
| Oct. -63 | aspen | common (small) | 0 | 0 | 0 | 0 | 0 | Most of the bark still alive. |
| June -64 | » | common (old and new) | single | 0 | 0 | 0 | 0 | Logs shedding their bark. *Myxomycetes* sp., (grey, fruiting) observed. |
| Oct. -64 | » | general | few | 0 | 0 | single | 0 | *Corticiaceae* sp., *Flammula alnicola* and *Myxomycetes* sp. (red) observed. |
| May -65 | » | general | common | 0 | 0 | few | few | *Corticiaceae* sp. and *Coryne sarcoides* observed. |
| Sept. -65 | » | general | common (old) | 0 | 0 | few | few | *Corticiaceae* sp., *Coryne sarcoides* (at the heart limit) and *Poria* sp. observed. |

Vuollerim

| Date | Type of wood | Frequency of logs with sporophores of the most common decay fungi | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | *Corticium* spp. | *Stereum purpureum* | *Libertella betulina* | *Stereum hirsutum* | *Polyporus zonatus* group | *Peniophora incarnata* | |
| Oct. -63 | birch | few | 0 | 0 | 0 | 0 | 0 | Areas of living bark occurring. *Trichoderma* sp. observed. |
| June -64 | » | few | 0 | common | 0 | 0 | 0 | |
| Oct. -64 | » | common | 0 | common (fragm.) | few (small) | 0 | 0 | |
| May -65 | » | common (covering great areas) | 0 | 0 | few | 0 | 0 | |
| Oct. -63 | aspen | 0 | 0 | 0 | 0 | 0 | 0 | Most of the bark still alive. |
| June -63 | » | 0 | 0 | 0 | 0 | 0 | 0 | Areas with living bark occurred. |
| Oct. -64 | » | few | few | 0 | 0 | 0 | 0 | Areas with living bark occurred. |
| May -65 | » | common | few | 0 | 0 | 0 | 0 | |

frequent until the second, growing season. At the beginning of the second growing season, orange-coloured spore masses, cirri, of *Libertella betulina* Desm. began to develop. During the second growing season cirri of this fungus were observed emerging from lenticels on almost every birch log. *Libertella betulina,* which has proved capable of decomposing birch wood in laboratory decay tests (HENNINGSSON 1967), has hitherto been neglected in Scandinavian literature on stored pulpwood. It has, however, been reported as very common on unpeeled birch wood in Russia (VAKIN 1964), and recently in Norway (personal communication from Dr. F. ROLL-HANSEN at the Norwegian Forest Research Institute). Towards the end of the second and during the third growing season, sporophores of *Stereum hirsutum* (Willd.) Fr. and the *Polyporus zonatus* (Nees) Fr. group developed. Because of variations in sporophore appearance the term "*Polyporus zonatus* group" has been preferred, involving sporophores ranging from a *Polyporus versicolor*-like appearance to typical *Polyporus zonatus* sporophores.

On the aspen wood, too, the *Corticium* species developed first of the decay fungi. Later, during the second season, *Stereum purpureum* formed sporophores which were especially common on the aspen wood in Ryd and Skinnskatteberg. *Polyporus zonatus* and *Peniophora incarnata* formed sporophores on some logs during the second and third growing seasons. According to HENNINGSSON (1967), the early-occurring species—*Corticium spp, Stereum purpureum* and *Libertella betulina*—decompose wood only slowly, whereas *Stereum hirsutum, Polyporus zonatus* and several other fungi which appeared relatively late on the wood, are much more active wood destroyers.

### C. Observations on the microflora in the wood.

After isolation of the micro-organisms growing out from the wood cores, it became evident that in addition to decay fungi, a number of non-*Basidiomycetes* and bacteria had invaded the stored logs. It was not possible to identify all these microbes, other than the most common *Basidiomycetes* and a few common *Ascomycetes*. Since the microscopical characteristics of the mycelia of *Polyporus zonatus* and *Polyporus versicolor* are most identical, such mycelia have been reported as belonging to the *Polyporus zonatus* group.

Mycelia of decay fungi were often isolated from the wood after only three months' storage, and generally several months before sporophores of these species were observed on the logs (Fig. 5). The decay fungi occurred in the logs in a sequence similar to that of the occurrence of

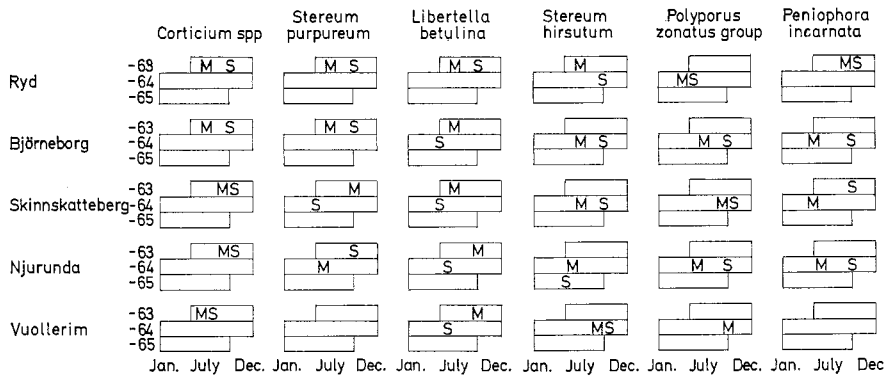


Fig. 5. Approximate time of the first recording of mycelia (M) and sporophores (S) of the most common decay fungi on the birch logs.

**Tab. 3. Moisture content of the stored wood and of the corresponding sound wood.**

| Storage place | Type of wood | Average original moisture content per cent | Moisture content of logs in per cent of the dry weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | July -63 | Oct. -63 | Feb. -64 | May -64 | July -64 | Oct. -64 | May -65 | Oct. -65 |
| | Birch | | | | | | | | | |
| Ryd | original | 91 | 93 | 85 | 89 | 92 | 90 | 98 | 91 | 88 |
| | stored | | 65 | 58 | 61 | 52 | 48 | 60 | 60 | 51 |
| Björneborg | original | 85 | 82 | 88 | 90 | 81 | 81 | 85 | 84 | 87 |
| | stored | | 68 | 71 | 75 | 66 | 61 | 65 | 67 | 67 |
| Skinnskatteberg | original | 85 | 89 | 83 | 87 | 83 | 85 | 83 | 82 | 86 |
| | stored | | 66 | 63 | 65 | 62 | 57 | 66 | 68 | 64 |
| Njurunda | original | 91 | 90 | 92 | 91 | 92 | 94 | 90 | 93 | 89 |
| | stored | | 69 | 60 | 63 | 58 | 55 | 58 | 59 | 62 |
| Vuollerim | original | 86 | 87 | 88 | 89 | 88 | 84 | 87 | 87 | 82 |
| | stored | | 69 | 62 | 62 | 63 | 54 | 57 | 65 | 58 |
| | Aspen | | | | | | | | | |
| Ryd | original | 118 | 121 | 119 | 120 | 112 | 113 | 122 | 118 | 121 |
| | stored | | 83 | 81 | 72 | 64 | 52 | 44 | 42 | 31 |
| Björneborg | original | 93 | 97 | 88 | 94 | 91 | 93 | 91 | 91 | 96 |
| | stored | | 76 | 73 | 73 | 66 | 55 | 56 | 56 | 52 |
| Skinnskatteberg | original | 106 | 103 | 108 | 104 | 107 | 102 | 106 | 108 | 108 |
| | stored | | 82 | 80 | 72 | 80 | 55 | 70 | 63 | 50 |
| Njurunda | original | 84 | 83 | 84 | 77 | 81 | 84 | 81 | 81 | 80 |
| | stored | | 58 | 57 | 58 | 46 | 39 | 49 | 44 | 42 |
| Vuollerim | original | 84 | 83 | 84 | 77 | 87 | 90 | 83 | 83 | 86 |
| | stored | | 68 | 68 | 60 | 65 | 55 | 54 | 54 | 42 |

sporophores on the logs. The *Corticium* species, *Stereum purpureum* and *Libertella betulina* were usually isolated from the birch wood during the first storage season. Later, mycelia of *Stereum hirsutum* and *Polyporus zonatus* were found. Towards the end of the storage period these latter species became very common, whereas the early-occurring fungi were rarely isolated. It is interesting to note that neither mycelia nor sporophores of *Stereum purpureum* and *Peniophora incarnata* were found in the Vuollerim material.

### D. Changes in moisture content during storage.

By weighing the disks wet and dry, their moisture content in per cent of the dry weight was determined. Tab. 3 shows that the average original moisture content of the wood varied between the storage places. This was especially pronounced for aspen wood. Tab. 3 also shows that there was some variation in the average original moisture content of the ten logs withdrawn from any one storage place on each sampling occasion. When comparing the changes in moisture content of the two species and the five storage places, these variations in the original moisture content were avoided by using the relative moisture content, i.e. the moisture content of the logs withdrawn at each sampling, expressed in per cent of the moisture content of the original sound wood of the logs. The results are presented in Fig. 6. It is evident that the birch and aspen wood dried about equally rapidly during the first summer's storage. During the first winter there was usually an increase in the moisture (uptake of water) of the wood, except in the aspen wood stored in Ryd and Björneborg, where a slow decrease was recorded. From the beginning of the second summer (the third summer in Vuollerim) the drying curves for birch and aspen diverged considerably. Whilst the aspen wood dried rapidly, the birch wood dried very slowly during the second summer. This difference certainly resulted from the general shedding of bark, which began on the aspen logs during the second year of storage. Fig. 6 also shows that the birch wood dried most rapidly in Ryd and Njurunda and that the aspen wood dried much faster in Ryd than in any other of the storage places.

### E. Changes in dry density during storage.

In calculating the dry densities, each of the five disks taken from a log was treated separately. The dry density of a whole log was assumed to be the average of the dry densities of each disk. The relative dry density of a stored log was determined in per cent of the average dry

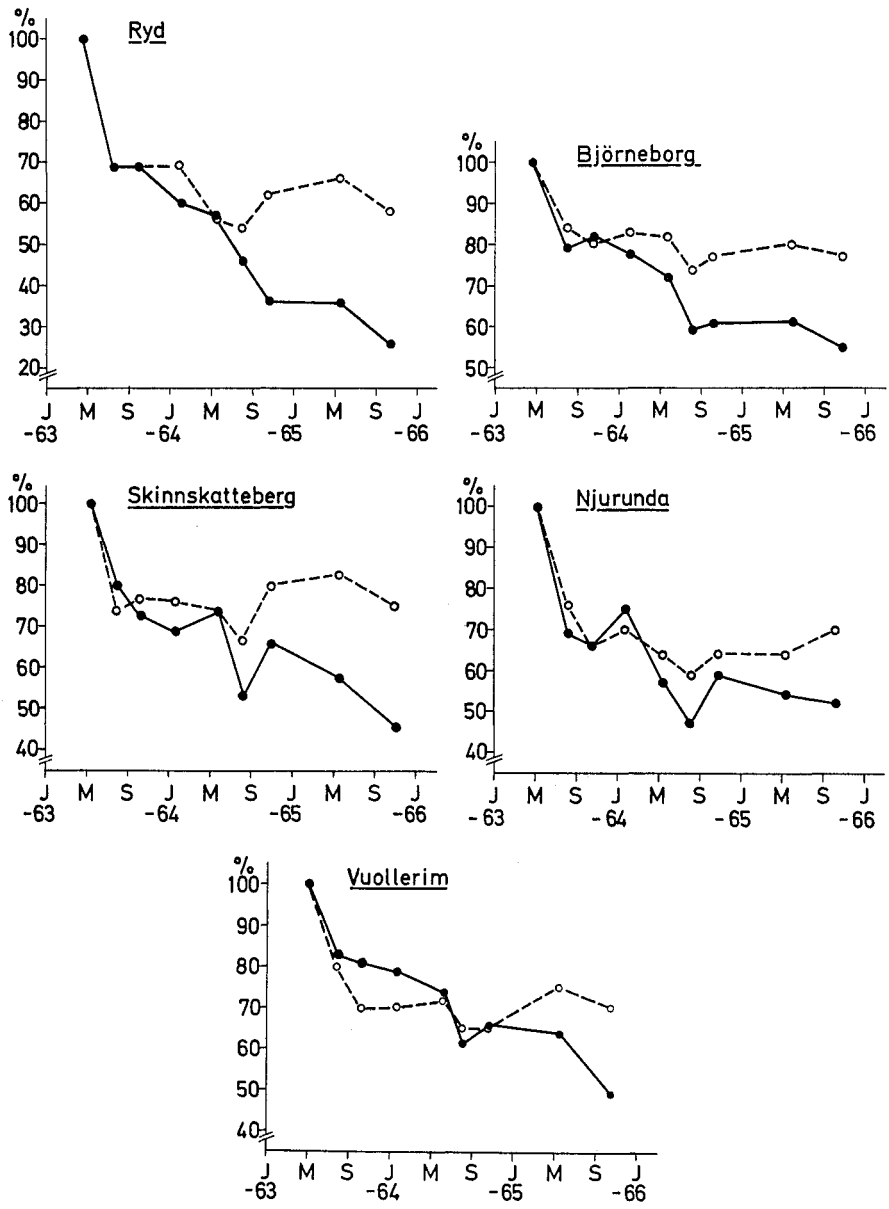


Fig. 6. Changes in moisture content of the birch (○) and aspen (●) logs during storage. The moisture content was calculated in per cent of the original moisture content of the log.

**Tab. 4. Decrease in dry density of the logs. Each value was calculated on the basis of the dry density of the original sound wood samples.**

**Birch**

| Storage place | Average original dry density g/cm³ | Average decrease in dry density, per cent | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Summer -63 | Autumn -63 | Winter -64 | Spring -64 | Summer -64 | Autumn -64 | Spring -65 | Autumn -65 |
| Ryd | 0.616 | 1.2 | 1.4 | 6.0 | 10.5 | 11.4 | 14.9 | 14.6 | 24.9 |
| Björneborg | 0.597 | 0.1 | 0.6 | 3.0 | 3.0 | 3.5 | 7.9 | 11.6 | 15.7 |
| Skinnskatteberg | 0.599 | – 0.5 | 0.8 | 5.6 | 5.2 | 8.4 | 8.7 | 9.6 | 17.2 |
| Njurunda | 0.576 | — | — | — | — | — | — | — | — |
| Vuollerim | 0.617 | – 0.4 | 0.0 | 2.7 | 4.1 | 4.1 | 3.7 | 9.1 | 11.1 |

**Aspen**

| Storage place | Average original dry density g/cm³ | Average decrease in dry density, per cent | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Summer -63 | Autumn -63 | Winter -64 | Spring -64 | Summer -64 | Autumn -64 | Spring -65 | Autumn -65 |
| Ryd | 0.450 | – 0.4 | 0.8 | 0.9 | 2.8 | 3.0 | 4.7 | 6.9 | 10.3 |
| Björneborg | 0.495 | – 0.8 | 0.1 | 0.9 | 2.0 | 0.8 | 2.9 | 3.5 | 6.4 |
| Skinnskatteberg | 0.432 | — | – 0.7 | 2.3 | 2.3 | 2.6 | 5.9 | 5.7 | 13.9 |
| Njurunda | 0.469 | 1.4 | 1.2 | 2.3 | 1.7 | 2.4 | 3.6 | 4.9 | 6.4 |
| Vuollerim | 0.463 | 0.7 | 1.5 | 2.5 | 1.2 | 3.8 | 2.1 | 4.3 | 5.1 |

densities of the two disks taken from the log at the beginning of the experiment. The values reported in Tab. 4 and Fig. 7 are the average of the ten logs withdrawn at each sampling. Disregarding a slight change in the shrinkage properties of the heavily attacked wood, the percentage decrease in dry density can be used as a crude measure of the percentage loss of wood substance caused by the metabolic activities of the micro-organisms. Fig. 7 and Tab. 4 clearly demonstrate that there was a decrease in the dry density of the pulpwood during storage. This decrease in dry density generally proceeded at a rate which increased with increasing storage time. It appears also that the rate of wood-decomposition, measured as a decrease in dry density, was higher for birch than for aspen and higher in Ryd than in any other of the storage places. Furthermore, the decrease in dry density was usually least in the northernmost storage place, Vuollerim.

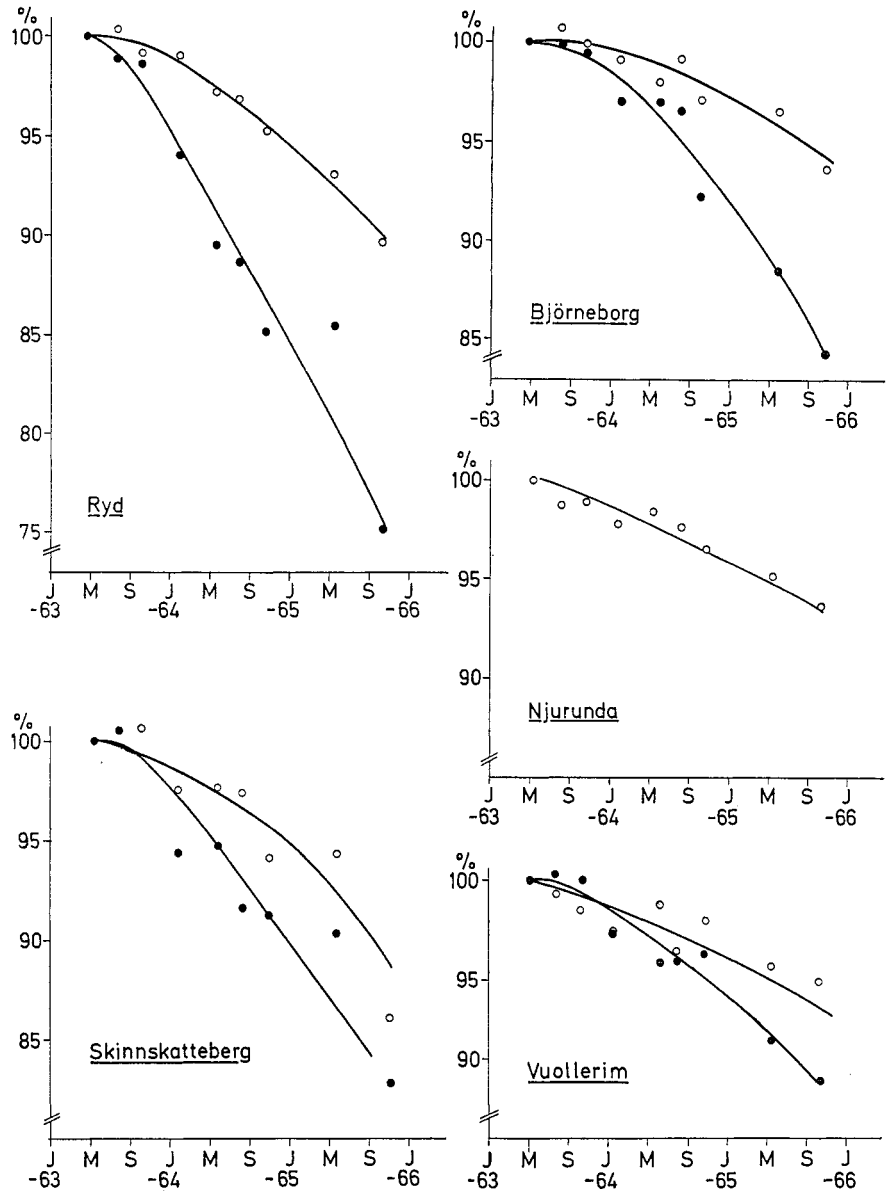


Fig. 7. Dry densities of the birch (●) and aspen (○) logs withdrawn on the various sampling occasions. The dry density of the corresponding sound wood samples was assumed to be 100 per cent.

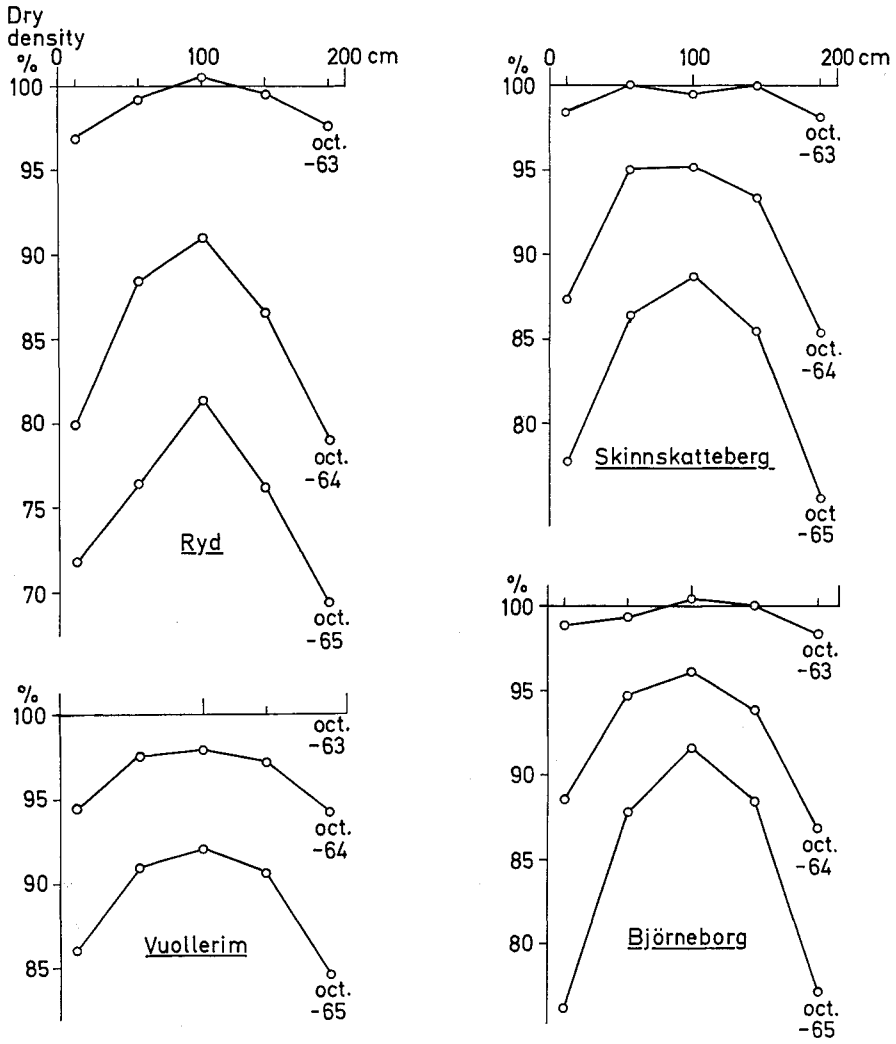


Fig. 8. Dry densities in different parts of the birch logs on three sampling occasions. The dry density of the sound wood was assumed to be 100 per cent.

Fig. 8 shows the average relative dry densities of the five disks taken from each birch log. It is evident that the wood decomposition mainly advanced from the end surfaces of the logs inwards, since the decrease in dry density was always most pronounced near the end surfaces, and least in the middle. This was less frequently the case

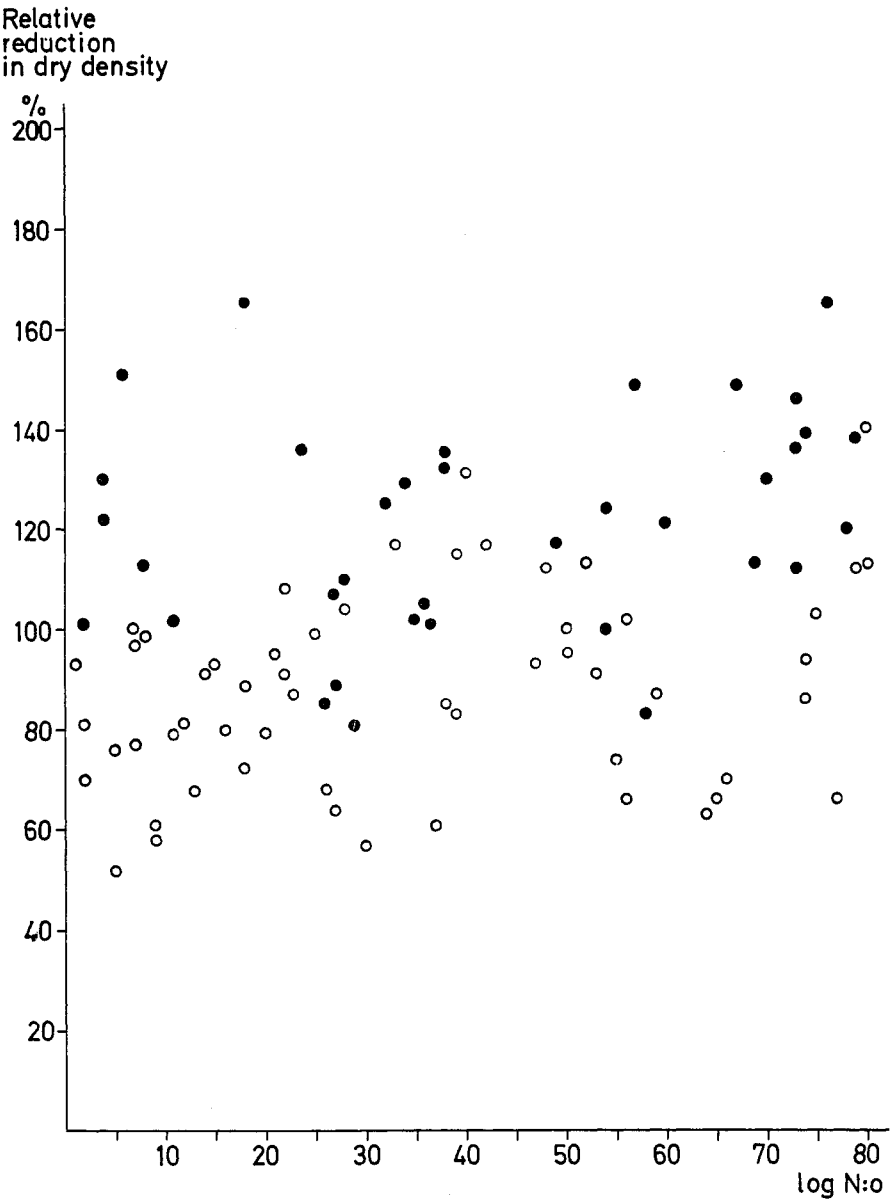


Fig. 9. Relative reduction in dry density of logs with (●) and without (○) branch scars. Birch logs withdrawn on the three last sampling occasions in Ryd, Björneborg and Skinnskatteberg are shown. The relative decrease in dry density of a log was calculated in per cent of the average for the logs withdrawn on each sampling occasion.

**Tab. 5. Cellulose and lignin contents (w/w) of the stored wood and of the corresponding sound wood. Figures within parantheses show the average decrease in dry density of the stored wood.**

| Type of wood and Storage place | Cellulose content, per cent | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Autumn -63 | | Spring -64 | | Autumn -64 | | Spring -65 | | Autumn -65 | |
| | Sound wood | Stored wood | Sound wood | Stored wood | Sound wood | Stored wood | Sound wood | Stored wood | Sound wood | Stored wood |
| *Birch* | | | | | | | | | | |
| Ryd | 40.4 | 41.1 (1.6) | 41.4 | 41.4 (9.8) | 40.3 | 41.0 (13.4) | 41.9 | 42.3 (11.8) | 40.9 | 39.6 (27.8) |
| Björneborg | 41.2 | 41.2 (0.6) | 40.7 | 41.1 (2.8) | 40.9 | 41.3 (7.9) | 41.5 | 41.8 (12.3) | 41.1 | 40.6 (15.6) |
| Skinn-skatteberg | 41.9 | 41.9 (0.9) | 39.8 | 40.1 (6.2) | 40.5 | 40.8 (8.7) | 41.3 | 41.8 (10.0) | 41.0 | 40.3 (19.5) |
| Njurunda | 39.2 | 39.1 | 40.2 | 40.1 (3.0) | 41.6 | 41.2 (3.8) | 38.2 | 38.2 (2.5) | 39.9 | 41.2 (10.9) |
| Vuollerim | 43.2 | 42.7 (0.1) | 42.8 | 42.6 (2.8) | 41.2 | 42.1 (2.1) | 41.6 | 42.5 (7.3) | 41.9 | 42.0 (11.7) |
| *Aspen* | | | | | | | | | | |
| Ryd | 44.7 | 45.0 (0.3) | 44.9 | 45.3 (3.2) | 45.1 | 44.6 (6.6) | 44.7 | 44.2 (5.3) | 44.9 | 45.3 (10.7) |
| Björneborg | 46.0 | 46.3 (0.6) | 45.7 | 46.0 (1.6) | 46.4 | 46.5 (3.1) | 46.4 | 45.9 (2.3) | 46.1 | 47.1 (8.4) |
| Skinn-skatteberg | 45.5 | 45.4 (1.0) | 45.4 | 46.4 (1.3) | 46.9 | 46.2 (5.1) | 46.9 | 46.9 (5.4) | 46.1 | 44.6 (14.5) |
| Njurunda | 48.6 | 48.2 (1.8) | 47.9 | 47.9 (3.3) | 49.7 | 48.1 (3.6) | 47.6 | 45.4 (5.4) | 48.5 | 45.5 (5.7) |
| Vuollerim | 46.0 | 46.0 (-1.0) | 45.9 | 46.0 (-0.8) | 46.0 | 46.5 (1.7) | 45.8 | 45.9 (4.1) | 45.9 | 45.6 (3.6) |
| | Lignin content, per cent | | | | | | | | | |
| *Birch* | | | | | | | | | | |
| Ryd | 21.2 | 21.2 | 19.4 | 19.4 | 20.7 | 20.9 | 20.1 | 19.7 | 20.4 | 20.0 |
| Björneborg | 20.0 | 19.6 | 20.1 | 19.8 | 19.5 | 19.5 | 19.7 | 19.0 | 19.8 | 20.3 |
| Skinn-skatteberg | 19.6 | 19.8 | 19.8 | 20.2 | 21.0 | 20.8 | 20.9 | 19.5 | 20.2 | 20.3 |
| Njurunda | 19.8 | 19.9 | 19.7 | 19.9 | 20.0 | 20.2 | 20.3 | 20.7 | 19.9 | 20.0 |
| Vuollerim | 18.6 | 18.9 | 18.4 | 19.2 | 18.5 | 19.0 | 19.3 | 19.2 | 18.8 | 18.9 |
| *Aspen* | | | | | | | | | | |
| Ryd | 20.6 | 20.2 | 20.7 | 20.4 | 20.7 | 20.9 | 20.9 | 21.2 | 20.8 | 20.5 |
| Björneborg | 19.0 | 19.1 | 19.2 | 19.1 | 19.6 | 19.7 | 19.8 | 20.0 | 19.4 | 18.0 |
| Skinn-skatteberg | 20.1 | 20.0 | 19.9 | 20.0 | 20.1 | 20.2 | 19.4 | 19.4 | 19.8 | 20.4 |
| Njurunda | 17.9 | 18.2 | 18.2 | 18.7 | 18.2 | 18.5 | 18.1 | 19.0 | 18.2 | 19.6 |
| Vuollerim | 20.5 | 19.6 | 19.5 | 19.8 | 19.4 | 19.3 | 20.4 | 20.1 | 19.8 | 19.4 |

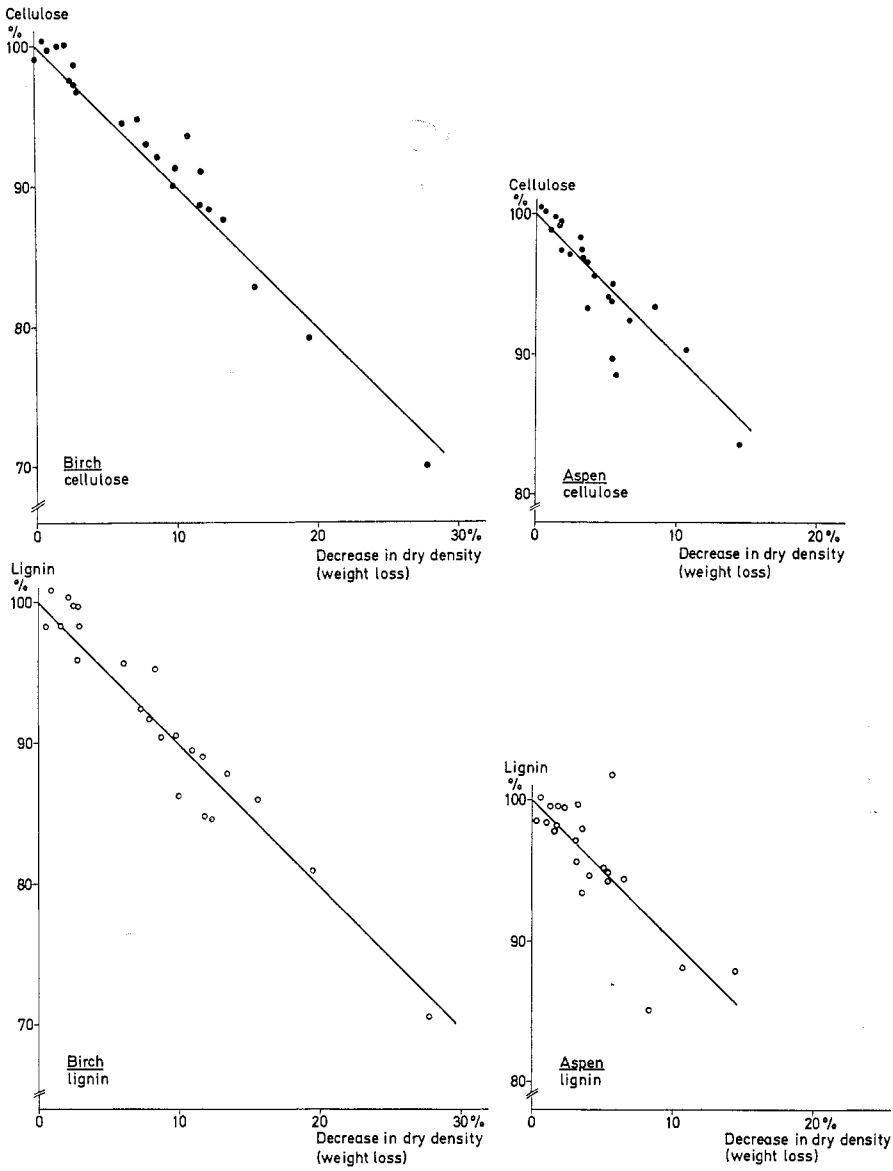


Fig. 10. Relative lignin and cellulose contents of the stored wood, based on the contents in original sound wood. All five storage places included. The lines corresponding to the theoretical decomposition rate of lignin and cellulose for a complete correlation with total wood decomposition are drawn.

with aspen wood, probably as a result of the large number of branch scars and the general shedding of bark during the second year of storage.

The importance of branch scars as gateways for infection by wood-destroying micro-organisms is demonstrated in Fig. 9. Birch logs taken only from the piles in Ryd, Björneborg och Skinnskatteberg on the last three sampling occasions have been considered. The reduction in dry density was generally greater in logs with branch scars than in logs without branch scars.

### F. Cellulose and lignin content.

The cellulose and lignin contents of the logs before (sound wood) and after storage are reported in Tab. 5. The values given in the table are the average of the five logs withdrawn on each sampling occasion. The results show that the cellulose and lignin content changed very little during the period of storage. In the first two years of storage, however, the cellulose content of the stored birch wood was often slightly higher than that of the corresponding original sound wood. This indicates that cellulose and lignin were decomposed about equally rapidly by the micro-organisms in the wood.

Assuming that the decrease in dry density corresponds to an equal loss of wood substance (weight loss), it is possible to calculate the loss of cellulose and lignin during storage. This was done for each sampling occasion at each storage place and the values were plotted against the decrease in dry density (weight loss) in Fig. 10. The line corresponding to the theoretical decomposition rate of lignin and cellulose for a complete correlation with total wood decomposition was drawn. The rate of decomposition of lignin and cellulose roughly follows this line, although the rate of early cellulose decomposition seems to be somewhat lower than the rate of total wood decomposition. Fig. 10 thus demonstrates that if the percentage decrease in dry density of stored unpeeled birch and aspen pulpwood is known, one has also a crude measure of the loss of cellulose and lignin from the wood, caused by micro-organisms, independent of storage conditions (viz. climate, and geographical location of the storage place).

## Discussion

The substantial differences in the rate of wood decomposition between the storage places, as measured in terms of decrease in dry density, reported in Tab. 4 and Fig. 7, are no doubt caused by climatic factors, the length of the growing season being most important. The rate of decomposition of birch wood during the period May 1963 to October 1964 in Ryd was, for instance, two to three times faster than in Björneborg and Skinnskatteberg and two to four times faster than in Vuollerim. These results should be considered in relation to the finding that in Ryd the growing season was about two months longer than that in Björneborg and Skinnskatteberg and nearly four months longer than that in Vuollerim (Fig. 3).

The results of the moisture content measurements on birch wood, reported in Tab. 3 and Fig. 6, indicate that the differences in rate of seasoning between the storage places were too small to exert more than a minor influence on the rate of wood decomposition (cf. HENNINGSSON 1967 b). In aspen wood, however, the differences in rate of seasoning were greater, and might have influenced the rate of decomposition, especially in Ryd, where the moisture content towards the end of the storage period approached the fibre saturation point.

Contributary causes to the slower decomposition of aspen wood compared with birch wood (Fig. 7 and Tab. 4) were that the aspen bark remained alive, for the most part, during the first summer of storage and that aspen heartwood is naturally decay-resistant (HENNINGSSON 1967 b).

Taking into account that the decay mainly advanced from the log ends, the length of the log plays an important part as regards the rate of wood decomposition. The longer is the log, the less decay there will be. This was also realised by BJÖRKMAN 1953 and HEISKANEN 1959.

The effect of felling time on the amount of storage decay has been studied earlier (cf. BJÖRKMAN 1953 and HEISKANEN 1959) and found to be of very little importance, provided that the logs felled at different times are stored equally long; and that this storage exceeds one year. Further research would, however, be of value for determining the effect of felling time on the development of decay, since factors like the annual fluctuations in moisture and nutrient content of the trees

(PETERSON & WINQVIST 1960) and in the amount of spores in the air (cf. MATHIESEN-KÄÄRIK 1955) might be expected have some influence.

The observations of the fungus flora in the logs showed clearly that the wood was invaded initially by fungi with low wood-destroying activity, and that severe wood destroyers did not invade until a certain period of storage had passed. This leads to very slow wood decomposition in the early stages of storage (Fig. 7).

Even if the biochemical activity in wood of some only of the decay fungi listed in Tab. 2 has been thoroughly investigated, most of them have been reported to possess polyphenol oxidising ferments (KÄÄRIK 1965), said to be a characteristic of the white rot fungi.

Thus almost all decay fungi found in the stored birch and aspen wood can be referred to as white rots. The species found in the present material were much the same as those found earlier in stored birch and aspen by, amongst others, BJÖRKMAN (1953 and 1958), GIORDANO et al. (1963) and HENNINGSSON (1962). It is well known that typical white-rot fungi attack cellulose and lignin in the wood simultaneously (cf. COWLING 1961, SEIFERT 1966) without significantly changing their proportions.

Considering the known composition of the fungus flora and the type of chemical wood decomposition typical of the individual fungi, it is not surprising that the proportions of lignin and cellulose changed very little during storage (Tab. 5), and that the loss of lignin and cellulose proceeded at the same rate as the total loss of wood substance (decrease in dry density). Thus, since the figures for decrease in dry density reported in Tab. 4 are valid on the whole for the loss of cellulose, too, it may be concluded that substantial amounts of the original cellulose might be lost during storage of unpeeled birch and aspen pulpwood, and that proper management and wood preservation must be of great economic importance.

## Summary

Unpeeled birch and aspen pulpwood logs two metres in length were stored in five places in Sweden in close stacks from May 1963 to Oct. 1965. The micro-flora invading the logs, changes in moisture content, decrease in dry density and the lignin and cellulose content of the wood were followed during storage. Owing to the presence of bark, seasoning of the birch wood was slow, whereas, as a result of bark-shedding, the seasoning of aspen wood was faster. The wood decomposition, measured in terms of the decrease in dry density, was greatly influenced by the length of the annual microbial growing season, wood decomposition being two to four times faster in the southern than in the northern part of Sweden. Decay advanced mainly from the end surfaces of a log inwards, indicating that, from the storage point of view, long logs are to be preferred to shorter ones.

The decay fungi attacking both types of wood were almost exclusively of the white rot type, resulting in a decomposition of cellulose and lignin which proceeded at the same rate as the total wood decomposition, measured as a decrease in dry density. This indicates that by knowing the decrease in dry density of birch and aspen pulpwood, one has also a crude measure of the loss of cellulose caused by the micro-organisms during storage.

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# Sammanfattning

**Mikrobiell nedbrytning av obarkad björk- och aspmassaved under lagring**

Obarkad tvåmeters björk- och aspmassaved lagrades på fem olika platser i Sverige i klosslagda travar från maj 1963 till oktober 1964. Mikroflora, fukthalt, torrdensitet samt cellulosa- och ligninhalt hos virket studerades under lagringsperioden. Eftersom försöksmaterialet lagrades obarkat, torkade björkvirket mycket långsamt, medan aspveden, vars bark ofta lossnade och föll av under andra och tredje lagringsåret, torkade snabbare. Vednedbrytningen mätt som sänkning av torrdensiteten påverkades i stor utsträckning av den årliga mikrobiella vegetationsperioden. I södra Sverige fortskred vednedbrytningen två till fyra gånger snabbare än i nordligaste delen av landet. Rötan avancerade huvudsakligen från ändytorna och inåt i försöksbitarna, vilket tyder på att ur virkesvårdssynpunkt långa massavedbitar är att föredra framför korta.

Båda vedslagen angreps nästan uteslutande av s. k. vitrötesvampar, vilket resulterade i en procentuell förlust av vedens lignin och cellulosa av ungefär samma storlek som den totala vednedbrytningen mätt som sänkning av torrdensiteten. Detta innebär, att om man känner den procentuella sänkningen av torrdensiteten, så har man också grovt mått på den cellulosaförlust som orsakats av mikroorganismerna under lagringen.