Consortium Project

Effect of Storage on Pulpwood

Markku Mäkelä
Kari Korhonen
Katriina Lipponen

English version of Metsäteho Report 91 B
25.5.2000

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Consortium project: Metsäliitto Osuuskunta, Stora Enso plc, UPM-Kymmene plc

Keywords: storage of roundwood, rot in wood, chemical pulp manufacture

Helsinki 2000

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SUMMARY

The project looked into the matter of changes in wood properties, which take place in pulpwood felled and prepared in different seasons of the year, and the effects of these changes on the manufacturing of chemical pulp and the usage value of the wood. This project is continuation to the 1999 study entitled "*Varastolaho*, *esiintyminen ja vaikutukset*" (Storage rot: occurrence and its effects).

Storage piles of pulpwood were set up in Finland, Estonia and Latvia for the purposes of the study. The pulpwood was harvested from final felling operations carried out in different seasons of the year, mainly using mechanised systems. The target size of the storage piles of timber in Finland was 50 - 60 m^3 and in Estonia and Latvia 25 - 30 m^3.

In Finland, birch, spruce and pine pulpwood were placed in storage formations at five points in time. The pulpwood was felled in August and October of 1998 and in February, April and June of 1999. Storing of the wood continued until mid-October 1999. This being the case, the longest storage times were 14 months and the shortest were 4 months. In the case of Estonia and Latvia, the storage operation involved birch and pine pulpwood felled in August-September of 1998 and in the winter of 1999 (no pine pulpwood felled in winter was available in Latvia). Storage of the pulpwood continued in Estonia and Latvia until late November-early December of 1999, and so the storage times were 15 and 9 months.

The storage piles in Finland were examined at six points in time: in September 1998 and January, May, June, August and October of 1999. The piles in Estonia and Latvia were examined three times: in December 1998 and in June and November of 1999.

Results

Changes in moisture content

Irrespective of the felling time, all the pulpwood dried the quickest in early summer. The wood was at its driest in August after which the moisture content began to slowly increase towards the autumn. In the case of pine and spruce pulpwood, the moisture content decreased between late May and mid-August by about 20% units. The corresponding figure for birch was a little over 10% units. The final moisture content for all the pulpwood in the autumn was about the same, between 30 - 32%.

The initial and final moisture contents of the birch and pine pulpwood in Estonia and Latvia did not differ very much from that of the pulpwood stored in Finland. The same applied to wood harvested at different points in time. The final moisture content of both birch and pine pulpwood varied within the range of 27 - 33%, depending on when they had been felled.

Changes in dry-green density

Changes in dry-green density in Finland were monitored using the same billets, while in Estonia and Latvia the measurements were made from different billets. The dry-green density readings obtained in the study were fairly high considering the wood was pulpwood in the round; they corresponded to the density of chipped sawmill material. The fall in dry-green density during the observation period of half a year varied between 0% and 6% in Finland and between 1% and 8% in Estonia and Latvia, depending on the pulpwood species.

Rot and blue stain defects

Birch

Stored birch billets first manifested a pale brown stain, which generally stood out from the lighter-in-colour sound wood. The leading boundary of fungal infection came a little behind the stain defect.

The August-felled batch of birch began to manifest the spread of the stain defect already during the same autumn. Part of the hard rot began to go soft at the onset of summer, and this became accelerated in late summer.

October-and-February-felled batches of pulpwood manifested the stain defect and it began to spread extremely fast in the early summer, but then it stopped. The proportion of hard rot increased quickly in the early summer and slowed down towards the autumn. Soft rot began to develop from June onwards.

The April-felled batch of pulpwood showed a rapid and even spreading of rot throughout the summer. However, the rot did not become soft by October.

The June-felled birch pulpwood piles were mainly affected by the stain defect only and it spread quickly.

The Pärnu and Riga birch pulpwood piles were characterised by the stain defect and hard rot advancing more or less as in Finland, but at the end of the summer the proportion of soft rot increased clearly faster than in corresponding piles in Finland.

Spruce

The August-and-October-felled spruce pulpwood remained almost without defects until mid-May. Thereafter rot and blue stain began to spread but (contrary to pine) first relatively slowly and then accelerating towards the autumn.

The February-felled spruce remained well preserved up to mid-June. After that the development of rot and blue stain was about similar as in the previous case.

The April-felled spruce pulpwood manifested blue stain and hard rot after mid-June. Both spread relatively slowly during the summer.

The June-felled batch of pulpwood was infected by blue stain and rot soon after being felled. Towards autumn, both blue stain and rot spread a little faster in the June-felled spruce pulpwood than in the April batch.

The pulpwood piles in Pärnu and Riga did not include spruce pulpwood.

Pine

The August-October-and-winter-felled pine pulpwood batches manifested some blue stain by mid-May and very little hard rot. Thereafter, blue stain spread fast before levelling out in August. Hard rot spread slightly slower than blue stain. No soft rot was observed.

The April-felled pine pulpwood manifested significant defects only after mid-June: Blue stain and hard rot spread in the wood until October, blue stain spreading faster than rot.

The June-felled pine pulpwood became infected with rot a little more than pulpwood felled in April.

The Pärnu and Riga piles of pine pulpwood did not rot faster than the pulpwood in Finland.

Spreading of rot in billets

Rot in autumn- and winter-felled birch pulpwood began to spread fast from the ends and more slowly from the sides of the billets. Rot in spring- and summer-felled birch pulpwood began to spread fast also from the sides, apparently due to pronounced debarking. In the case of pine and spruce pulpwood billets, rot spread from the ends and sides fairly evenly irrespective of the felling time.

Factors affecting the degree of rotting in Finnish pulpwood

Logging time

The felling time and the length of the storage period had the most effect on the development of rot. The proportion of rot increased when the period of storage lengthened. The exceptions in the case of pine and spruce pulpwood were the batches which had been felled before the onset of the trees' vital functions (in April), and these kept better than those felled later in June.

Billet diameter, length and taper

With pine and spruce pulpwood billets, an increase in billet diameter was reflected as a decrease in the total amount of rot. With birch, increasing diameter had the opposite effect.

In the case of pine and spruce pulpwood billets, short billets rotted faster than long billets, whereas birch billets behaved the opposite.

Fast-tapering billets generally originate from the heavily-branched part of tree stems. There rot was present more than elsewhere.

Moisture content and dry-green density

In the case of birch, billets containing a lot of sound wood were more moist and heavier than billets containing little sound wood. An increase in soft rot significantly reduced both dry-green density and green density.

In the case of pine and spruce pulpwood, billets containing a lot of sound wood were drier than those that contained little sound wood. Pine billets containing a lot of rot were more moist than billets containing little hard rot. Pine billets containing a lot of sound wood had lower dry-green densities than those with a lot of blue stain.

Spreading of rot in pulpwood in Finland and in Estonia and Latvia

The models calculated with the collected material as the basis were used in determining changes in piles of pulpwood comparable as regards their time of felling. In the case of birch, the amount of soft rot at the beginning of the summer was more or less at the same level in Finland and in Estonia and Latvia. Soft rot spread considerably faster during the summer and autumn in Estonia and Latvia when compared to Finland. In the case of pine pulpwood, there was no consistent difference between the storage places.

1 INTRODUCTION

Logging is largely planned subject to the conditions imposed by the most valuable and least-durable-in-storage roundwood assortments. In such a situation, one is often compelled to harvest less valuable assortments to excess, e.g. pine and birch pulpwood. The excessive felling of these assortments leads to storage times, which can be quite long at times. The need to store wood intended for the manufacturing of chemical pulp and the amounts needing to be stored are increased also by imported wood arriving in an uncontrolled manner as regards arrival dates.

This project is continuation to the study completed in 1999 entitled "*Varastolaho, esiintyminen ja vaikutukset*" (Storage rot: occurrence and its effects). The study looked into the matter of storage rot of pulpwood felled in the winter and autumn; the pulpwood were of different origin, and logged and stored in different ways. The study revealed the effects of various factors in the onset and spread of rot. A further study was needed to provide additional observations from wood harvested and used in different seasons of the year. The project focused on looking into the changes taking place in the woody tissue of pulpwood of maximum consistency and their effects on the manufacturing of chemical pulp, and thereby on the converting value of the wood raw material.

A calculation method can be drawn up based on the results of the projects for calculating the change in the converting value of wood raw material as caused by storage.

2 IMPLEMENTATION

The study belongs to a series of studies on the subject of rot conducted at Metsäteho and the Finnish Forest Research Institute (Metla). Planning and implementation were also participated by Metsäliitto Osuuskunta, Stora Enso Metsä, Sunila Oy, UPM-Kymmene Metsä and UPM-Kymmene Pulp Center. In addition to financing provided by Metsäteho and the Finnish Forest Research Institute, partial funding was obtained from TEKES.

Metsäliitto, Stora Enso Metsä and UPM-Kymmene Metsä participated in the procurement and storage of the pulpwood included in the study (in Estonia the partner was Stora Enso Mets and in Latvia Stora Enso Mezs). The studies focusing on the changes in woody tissue were conducted at Metla assisted by Metsäteho. The chemical pulp trials were performed at UPM-Kymmene Pulp Center.

3 CHANGES IN WOODY TISSUE DURING STORAGE

3.1 Material and methods

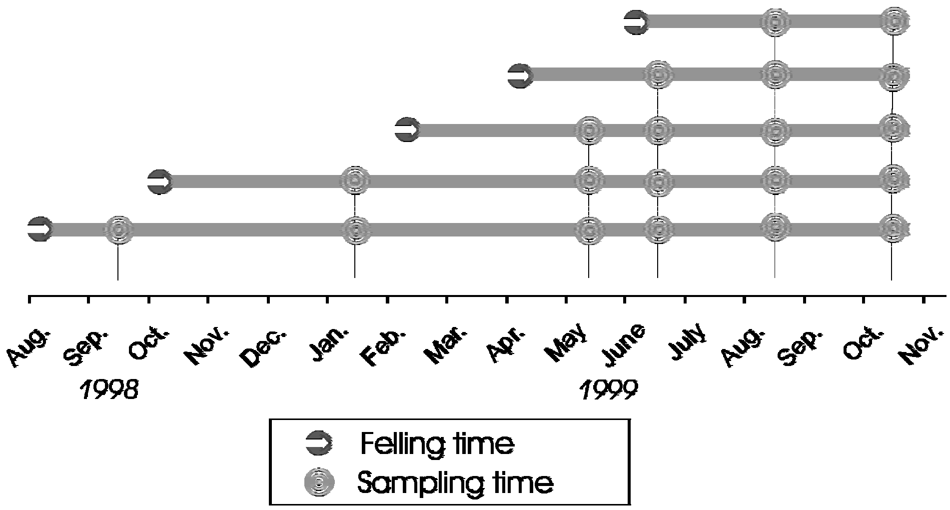
3.1.1 Stored pulpwood

Pulpwood storage piles were set up in for the purposes of this study in Finland, Estonia and Latvia; the wood stored was mainly harvested from final felling operations carried out in different seasons of the year using mechanised systems. The majority of the billets were 5 m in length, with some 3 m and 4 m lengths mixed in. In Finland, the storage point was located along a road near Tillola, Kouvola. In Estonia and Latvia, the pulpwood was stored at intermediate storage points for wood destined for Finland in Riga and Pärnu.

The target size of the piles of pulpwood was 50 - 60 m^3 in Finland and 25 - 30 m^3 in Estonia and Latvia, which did not, however, eventuate in all cases. In Finland, the study material comprised fifteen pulpwood piles, four in Estonia and three in Latvia, i.e. altogether twenty-two piles.

In Finland, birch, spruce and pine pulpwood were stored at five points in time. The trees were felled in August and October of 1998, and in April and June of 1999. The storage period lasted until mid-October of 1999. The longest periods of storage were 14 months and the shortest were 4 months.

In Estonia and Latvia, the storage involved birch and pine pulpwood felled in August-September of 1998 and in the winter of 1999 (winter-felled pine pulpwood was not available in Latvia). The period of storage continued in Estonia and Latvia until late November-early December of 1999, and so the storage periods were about 15 months and 9 months.



3.1.2 Sample billets

During storage, the changes taking place in woody tissue were studied by accessing sample billets of different sizes picked at random from different parts of the piles. The batch-specific target in Finland was to examine twenty billets and in Estonia and Latvia ten billets. At first, the number of sample pieces in the Finnish material fell short of the target due to lack of rot defects.

The pulpwood piles in Finland were examined six times: in September of 1998 and in January, May, June, August and October of 1999. The piles of pulpwood in Estonia and Latvia were examined three times: in December of 1998 and in the summer and November of 1999.

Bark damage and location of such damage on the stem (butt billet or some other billet) were first determined visually by examining the sample billets. To enable changes in the woody tissue to be examined, the billets were cross-cut at points 10, 60 and 100 cm from both ends and at the mid point. To determine the moisture content and the dry-green density, a disc about 5 cm in thickness was sawed off 60 cm from the butt end of the billet. Furthermore, the butt, top and mid diameters of the billets were measured, and for pine and spruce also the diameters of the heartwood section.

Colour defect, blue stain, and hard and soft rot proportions were assessed visually as percent of the cross-section areas at the cross-cutting points. Assessment with pine and spruce pulpwood focused on the area of sapwood because the heartwood was practically always sound. The majority of the assessments were made by the same person throughout the study.

3.1.3 Definitions of moisture content and dry-green density of the wood

In laboratory conditions, the sample discs were weighed when freshly cut (i.e. green) and their volumes were measured by immersing in water. Then the samples were dried in a heating chamber. The moisture content percentage was determined as the ratio of the weight of the water contained by the sample and its total weight.

Changes in moisture content, and especially in dry-green density, do not provide a complete picture if these are determined from different billets. This is due to the considerable billet-specific variation of these properties. In this study, the changes were determined by monitoring changes in the same billet.

Every one of the piles in the Tillola storage were sampled for ten random billets, which were then monitored regarding changes in moisture content and dry-green density. The billets were placed in a separate pile in the vicinity of the study storage. The material comprised 50 billets of birch, pine and spruce billets, i.e. a total of 150 billets.

The wood samples were taken in May, June, August and October of 1999 using an increment borer. Each billet was accessed for five sample cores. The first samples in May were taken from points 10 and 120 cm from the ends of the billets and from the mid point of each billet. The following sampling operations were made after about 5 cm from the previous borer hole. After the last boring made in October of 1999, discs were sawn from the boring point and the same measurement were made from the discs.

Sampling in Iitti (Finland). The sample billets were taken at random from the piles of pulpwood at the landing (r) to facilitate determining the changes taking place in the quality of the woody tissue. Photos: Metsäteho Oy

Determining of moisture content and dry-green density was done by accessing the same billets repeatedly.

Based on the results obtained from the billets thus sampled, the correlation between the physical properties (moisture content, dry-matter content and green and dry-green density) of the billets and sound wood, colour defects and hard and soft rot were tested using Pearson's correlation coefficient (Vasama and Vartia 1973).

3.1.4 Modelling of the development of storage rot

Storage rot development was modelled using a model based on the SPSS software's general linear model (Marija J. Norusis/SPSS Inc. 1993). The model was used to clarify how pulpwood properties (moisture content, billet length and increasing diameter) affect the development of rot during storage. Also, the model enabled the elimination of the variation caused by tree species when comparing the different felling times.

To begin with, we tested a model in which all the examined variables were included as variables explaining the variation: billet length, butt and top diameter, moisture content, bark damage, sampling times and felling times, and also the cross outcome of the latter two. The model was drawn up separately for sound wood and colour defects and for the total amount of rot and soft rot.

The effect of billet length and diameter on the development of rot was studied using a model in which bark damage and moisture content percent were omitted as explanatory variables. A similar model was drawn up for sound wood and for computing the amounts of colour defects.

3.2 Results

3.2.1 Billet dimensions and quality

Diameter: Apart from two birch pulpwood batches, which were of larger mean diameter than the others, there was no great variation in the Finnish material as regards average diameter. The autumn-felled pulpwood in Pärnu differed most of all from the others as regards billet size (Table 1).

TABLE 1 Average butt and top diameters and volumes of the examined billets in the various felling batches. The proportion of heart wood was obtained as the ratio between the sample billets' summed up heartwood volume and the total volume.

Tree species	Felling time	Butt diam. cm	Top diam. cm	Volume, litres	Heart-wood,%
TILLOLA					
Birch	August 98	14.2	10.5	63.3	
	October 98	16.3	11.9	84.4	
	January 99	16.8	12.9	87.4	
	April 99	13.7	8.8	50.2	
	June 99	13.0	8.6	46.7	
	Average	**14.8**	**10.5**	**66.0**	
Pine	August 98	16.6	11.6	84.3	26.6
	October 98	17.1	11.5	79.0	15.2
	January 99	15.2	11.3	70.6	25.5
	April 99	16.3	10.8	73.2	17.3
	June 99	14.8	9.9	66.0	16.5
	Average	**16.0**	**11.0**	**74.6**	**20.4**
Spruce	August 98	13.4	9.1	51.6	3.7
	October 98	15.7	10.5	68.9	13.6
	January 99	13.3	9.6	53.7	2.8
	April 99	14.2	9.9	59.0	7.6
	June 99	14.5	9.7	53.6	1.9
	Average	**14.2**	**9.8**	**57.4**	**6.4**
PÄRNU					
Birch	August 98	17.0	12.4	91.0	
	February 99	14.8	12.3	44.9	
	Average	**15.9**	**12.4**	**68.0**	
Pine	August 98	19.0	12.2	101.8	40.7
	February 99	15.8	12.1	47.3	22.7
	Average	**17.4**	**12.2**	**74.6**	**35.0**
RIGA					
Birch	August 98	14.5	11.7	42.3	
	February 99	12.6	9.3	31.2	
	Average	**13.6**	**10.5**	**36.8**	
Pine	August 98	13.9	11.0	38.9	10.5

Heartwood: There was considerable variation in the amount of heartwood between the different felling batches. There was more heartwood in the Estonian pine pulpwood and less in the Latvian pine pulpwood than in the Finnish pine pulpwood (Table 1). The large amount of heartwood in the Estonian pulpwood was mainly due to the large average diameter of the pulpwood batch felled in August of 1998.

Bark damage: Spruce pulpwood showed the least bark damage. Billets felled in the summer had clearly more bark damage than those felled in late autumn and winter (Fig. 1). Birch and pine pulpwood felled in Estonia and Latvia had less bark damage than in Finland. Estonian birch billets felled in late summer had extremely little bark damage, a mere 3.3%. The probable reason for this is that part of the pulpwood had been motor-manually felled.

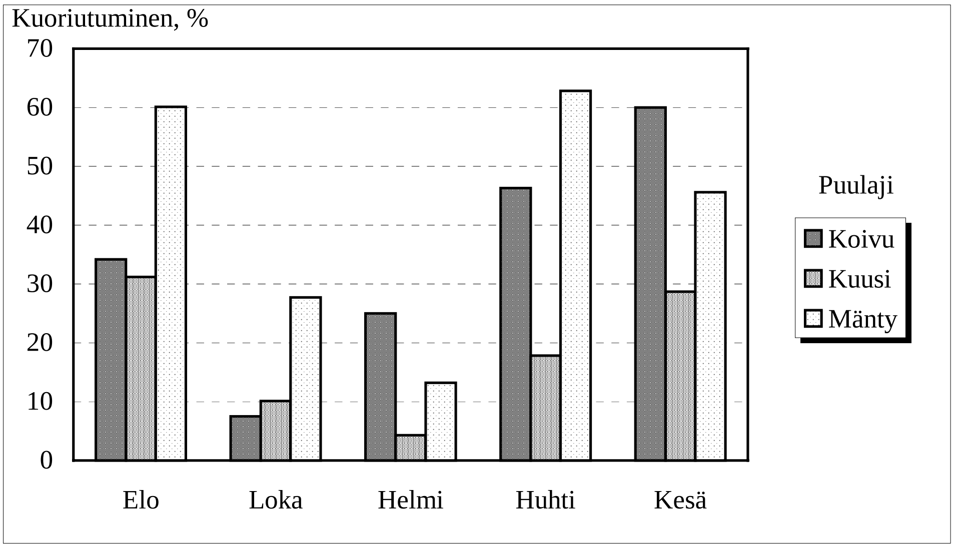


Figure 1. Average bark damage on birch, spruce and pine pulpwood billets felled at different points in time in Finland.

Kuoriutuminen = Bark damage
Puulaji = Tree species
August, October, February, April, June

3.2.2 Changes in moisture content

Regardless of the felling time, all pulpwood assortments dried the quickest during early summer. The wood was driest in August, after which its moisture content began to slowly rise towards autumn. In the case of pine and spruce, the moisture content dropped between the end of May and mid-August by about 20%. The corresponding fall in birch pulpwood was a little over 10%. The final moisture content for all three pulpwood assortments in the autumn was nearly the same, 30 - 32% (Fig. 2).

Birch pulpwood felled in the autumn before winter remained clearly more moist in storage than birch felled at other times of the year (Fig. 3). However, this batch of birch had less bark damage and its average diameter was greater than that of the others. The differences in moisture content between the pine and spruce batches felled at different points in time were not great when examined at a particular moment (Figs. 4 and 5, p. 18). The differences between the pine and spruce batches were smaller than within birch batches.

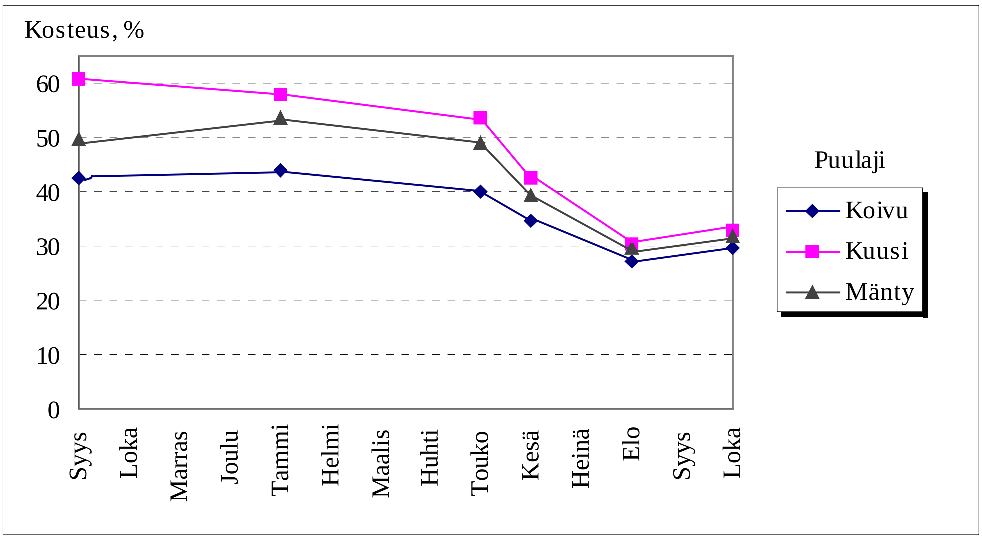


Figure 2. Average changes in the moisture content of the three pulpwood tree species. This is shown in the figures for the average ratio of the mass of the water contained in the wood and of the total weight of sample billets.

Kosteus, % = Moisture content, %
Puulaji = Tree species
Koivu = Birch
Kuusi = Spruce
Mänty = Pine
The time scale is from September 1998 to October 1999

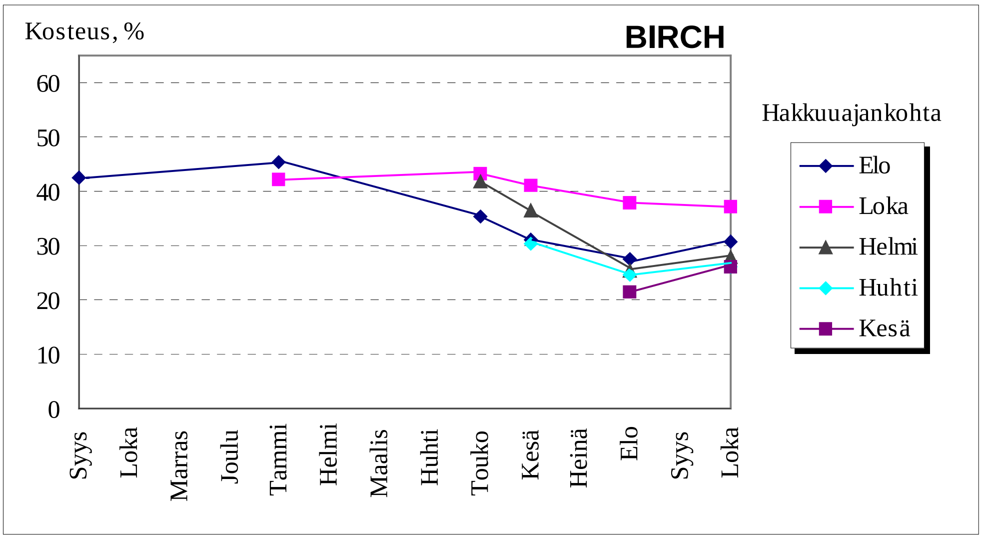


Figure 3. Changes in the moisture content of birch pulpwood felled in Finland at different points in time.

Hakkuuajankohta = Time when felled
Kosteus, % = Moisture content, %

The results for the parallel study material collected when monitoring changes in moisture content in the same sample billets were very similar for pulpwood of all tree species as those obtained for the pulpwood from the study piles. However, the moisture content figures were 3 - 4 percent lower on average. This difference may have been caused by the drying of the small core samples extracted using an increment borer before they were weighed or by the faster drying of billets stored in small piles as compared to those stored in large piles through the warm summer. The slower drying of the birch pulpwood batch felled in late autumn also became evident in this trial, as did the rise in moisture content of all pulpwood assortments by an average of approx. 2% after August.

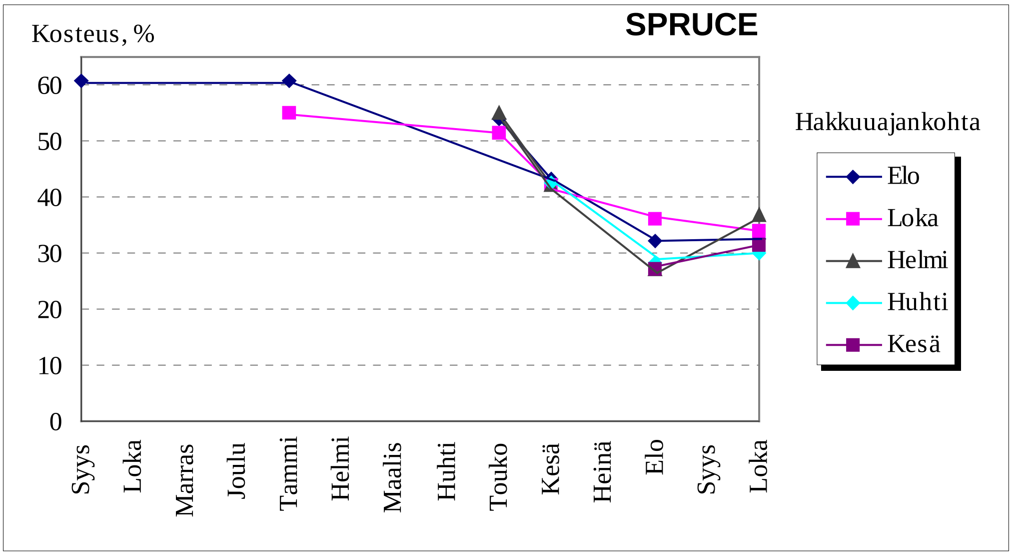


Figure 4. Changes in the moisture content of spruce pulpwood in Finland felled at different points in time.

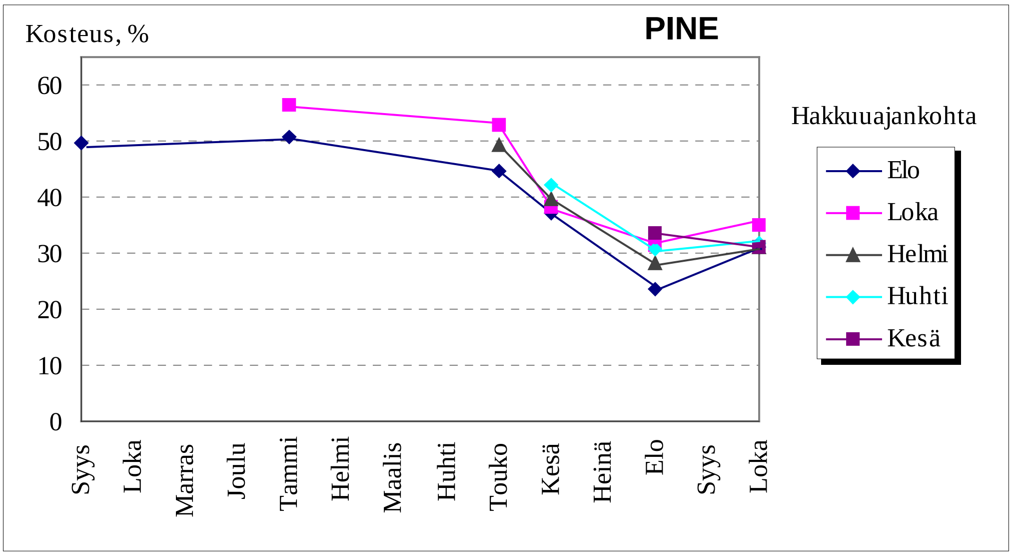


Figure 5. Changes in the moisture content of pine pulpwood in Finland felled at different points in time.

The initial and final moisture contents of birch and pine billets in Estonia and Latvia did not really differ from the results obtained for billets stored in Finland. Neither was there much difference between the batches of pulpwood felled at different points in time. In the case of both birch and pine pulpwood, their final moisture content varied, depending on the felling time, within the range of 27 - 33%.

3.2.3 Changes in dry-green density

The parallel Finnish material made it possible to follow the changes in dry-green density which took place in the same billets. The data collected in Estonia and Latvia were from different billets each time. The comparing of the various felling batches is made difficult by the fact that the batches of pulpwood felled the earliest both in Finland and in Estonia and Latvia had been stored over several winter months before their green density was determined. Also, the most recently felled sample trees (in the early summer of 1999) had been in storage for a couple of months before they were first sampled.

As decay in the wood progressed, determining the volume of the sample cores proved to be unreliable. There is reason for suspecting errors in regard to three batches of pulpwood whose dry-green density fell by more than 10%. The final dry-green density value for the Tillola pulpwood is based on dry-green densities measured from discs of wood sawn adjacent to the boring points, whereas the initial dry-green volumes are based on measurements made of the sample cores. The corresponding measurements for pulpwood stored in Estonia and Latvia were made of discs of wood 50 - 150 cm^3 in size sawn 60 cm from the butt end of sample billets.

The dry-green density results obtained were fairly high throughout for pulpwood; indeed, they corresponded more to the dry-green density values of wood chips as produced at sawmills (Lindblad and Verkasalo 1999). Depending on the tree species, the fall in dry-green density during the 6-month observation period was between 0% and 6% in Finland and 1% - 8% in Estonia and Latvia.

TABLE 2 Changes (± deviation) in the dry-green densities of the different felling batches of pulpwood stored in Finland and in Estonia and Latvia from mid-May of 1999 until the end of the study period (Tillola 13.10, Pärnu 30.11 and Riga 29.11.1999).

Tree species	Felling Time	Initial density, kg/m^3	Final density, kg/m^3	Fall in density, %
		TILLOLA		
Birch	August 98	514 ± 35	484 ± 47	6
	October 98	535 ± 26	531 ± 19	1
	February 99	513 ± 42	498 ± 23	3
	April 99	492 ± 20	494 ± 38	0
	June 99	574 ± 37	517 ± 40	10
	Average	**526 ± 32**		
Spruce	August 98	400 ± 43	396 ± 39	1
	October 98	409 ± 24	406 ± 18	1
	February 99	398 ± 45	389 ± 29	2
	April 99	446 ± 58	421 ± 31	6
	June 99	414 ± 35	403 ± 35	3
	Average	**413 ± 41**		
Pine	August 98	447 ± 55	424 ± 34	5
	October 98	441 ± 82	433 ± 38	2
	February 99	439 ± 51	416 ± 27	5
	April 99	433 ± 38	417 ± 32	4
	June 99	464 ± 30	411 ± 30	11
	Average	**445 ± 51**		
		PÄRNU		
Birch	August 98	517 ± 43	494 ± 24	4
	February 99	467 ± 21	460 ± 31	1
	Average	**492 ± 35**		
Pine	August 98	408 ± 42	403 ± 31	1
	February. 99	428 ± 72	415 ± 47	3
	Average	**418 ± 14**		
		RIGA		
Birch	August 98	502 ± 15	480 ± 43	4
	February 99	519 ± 23	457 ± 41	12
	Average	**511 ± 12**		
Pine	August 98	438 ± 39	405 ± 42	8

3.2.4 Rot defect and colour defects

Birch

The stored birch pulpwood contained hardly any blue stain. Instead, there was some pale brown stain, which generally stood out from the lighter-in-colour sound wood. The leading boundary of fungal infection came a little behind the stain defect.

<u>*August-of-1998-felled batch of birch*</u>: this pulpwood batch began to manifest the spread of the stain defect already during the same autumn (Fig. 6, p. 23). The proportion of stain defect and of hard rot was 34% by January of the following year and 65% by the middle of May (the colour defect and hard rot were combined because they were difficult to distinguish from one another). Part of the hard rot began to go soft at the onset of summer, and this change became accelerated in late summer. The proportion of sound wood in October was 5%, that of wood spoiled by colour defect and hard rot 73%, and that of wood spoiled by soft rot 22%.

<u>*October-of-1998-felled batch of birch*</u>: the proportion of colour defect was 2% in January and in May it was 12%. No hard rot was to be seen as yet. The colour defect spread extremely fast in early summer, but then stopped; the proportion of sound wood in billets examined after June remained more or less unchanged. The reason for this is unclear. The proportion of hard rot increased quickly in early summer and then slowed down towards the autumn. Soft rot began to develop from June onwards. In October, the proportion of remaining sound wood was 27%, that of soft rot was 8%, with the rest of the wood being spoiled by colour defect or hard rot.

<u>*February-of-1999-felled batch of birch*</u>: the development of rot defect was very similar to that observed in the October felling batch. Here, too, the colour defect spread rapidly in the early summer, but then in October it slowed down, but continued to spread until October.

<u>*April-of-1999-felled batch of birch*</u>: showed a rapid and even spreading of rot throughout the summer. In October there was even less (3%) of sound wood than in birch batches felled in the autumn and winter. However, the rot had not yet become soft.

<u>*June-of-1999-felled batch of birch*</u>: the spreading of the colour defect was faster still and in October there was only 7% of sound wood remaining. Almost all of the remaining wood was classified as being spoiled by colour defect; only 3% was classified as being hard rot.

<u>*Pulpwood stored in Pärnu and Riga*</u>: the pulpwood piles were characterised by the stain defect and hard rot advancing more or less as in Finland, but at the end of the summer the proportion of soft rot increased clearly faster than in corresponding piles in Finland (Fig. 7. p. 24).

Spruce

August-and-October-of-1998-felled batches of spruce: these remained almost unaffected until mid-May; the proportion of rot defect was less than 3% (Fig. 8, p. 25). Thereafter, rot and blue stain began to spread, but (contrary to pine) first relatively slowly and then accelerating towards the autumn. In October, between 30% and 50% of the wood was spoiled by hard rot. Soft rot was present only in the August-felled batch and even then less than 1%.

February-of-1999-felled batch of spruce: this batch remained well preserved until mid-June. The rot and blue stain spread slowly during the summer, faster towards the autumn.

April-of-1999-felled spruce pulpwood: this batch manifested blue stain and hard rot after mid-June. Both spread relatively slowly during the summer.

June-of-1999-felled batch of spruce pulpwood: this batch was infected by blue stain and rot soon after being felled. In August, however, there was still less than 4% of rot. Towards autumn, both the blue stain and the rot spread a little faster in the June-felled spruce pulpwood than in the April-felled batch.

Pärnu and Riga: spruce pulpwood was not examined.

Pine

August-October-of-1998 and winter-of-1999-felled batches of pine pulpwood: there was less than 10% of blue and less than 2% of hard rot by mid-May (Fig. 9, p. 26). Thereafter, blue stain began to spread fast and this continued, though at a slower rate, until August. Hard rot spread slightly slower than blue stain. In mid-August, only a small part of the sapwood was still sound, about half of the remaining wood being spoiled by blue stain and the other half by hard rot. In the autumn the spread of blue stain ceased. The spread of rot continued, but it remained hard; in October it had a spread of 33%-50%. Soft rot did not appear in pine pulpwood during the first summer.

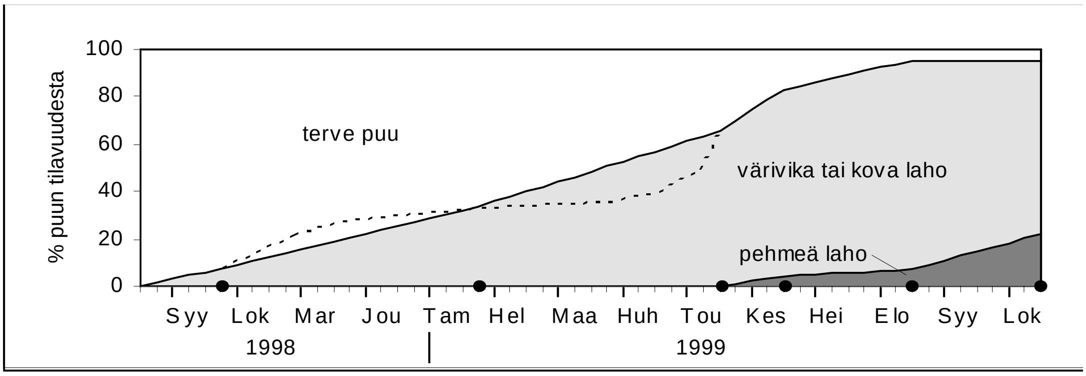
April-of-1999-felled pine pulpwood: this batch manifested significant defects only after mid-June: blue stain and hard rot spread in the wood until October, the blue stain spreading faster than rot.

June-of-1999-felled pine pulpwood: this batch became infected with rot a little more (18%) than the pulpwood felled in April (12%).

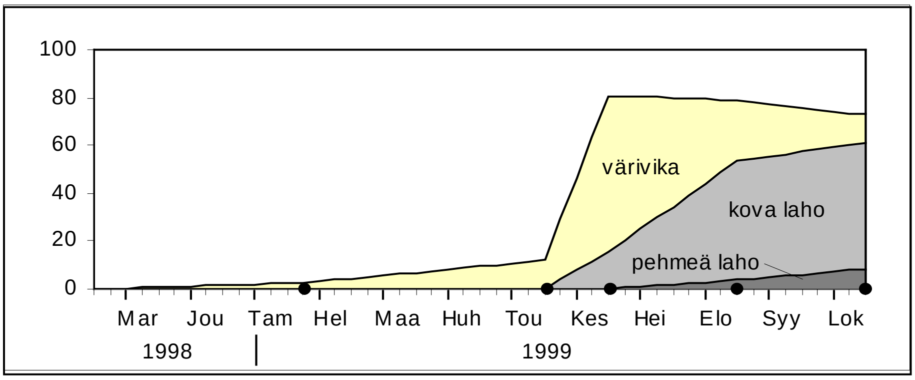
Parnu and Riga piles of pine pulpwood: these did not rot faster than the pulpwood in Finland. (Fig. 10, p. 27). In actual fact, the pile in Pärnu, felled in August of 1998, showed a slightly slower rate of rot than its counterpart in Finland. The billets in Pärnu were above-average in diameter and their heartwood proportion was high.

The overall spread of rot in the winter-felled batches of pulpwood in Estonia and Latvia was slower than in Finland; in the case of the August-felled batches it was a little faster.

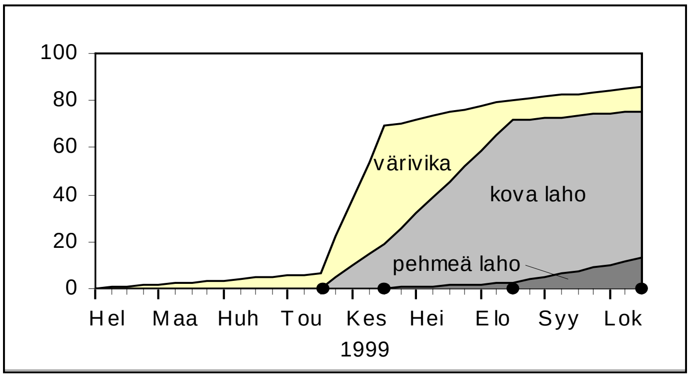
August 1998



October 1998

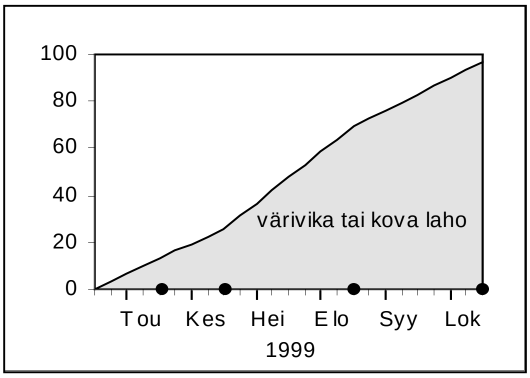


February 1999



terve puu = sound wood
värivika = colour defect
kova laho = hard rot
pehmeä laho = soft rot

April 1999



June 1999

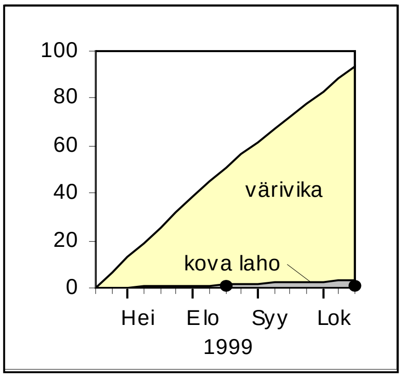
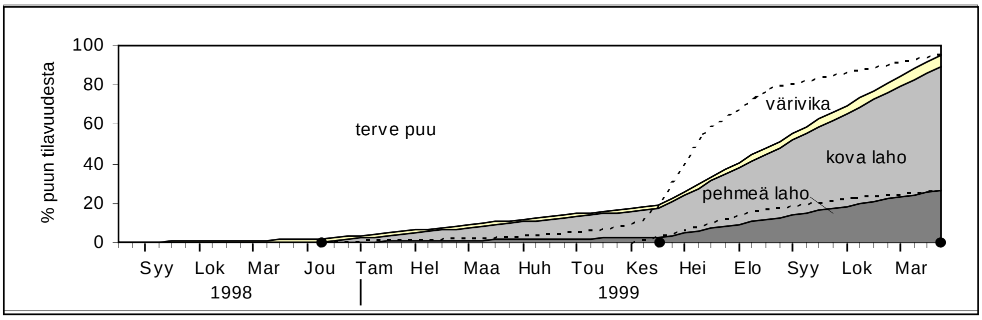


Figure 6. The spread of rot defect in piles of birch pulpwood felled at different points in time. The time axes begin from the felling time and the sampling points in time are marked on the axes. The August felling batch's dashed line points out the more probable development of the colour defect during winter when the wood was frozen. Due to difficulties in distinguishing them, the colour defect and hard rot are combined for the August and April felling batches.

BIRCH

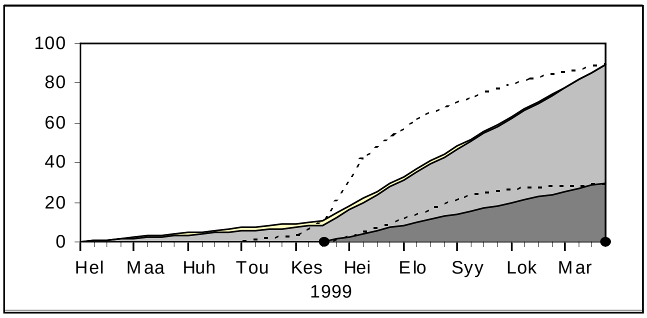
PÄRNU

August
1998



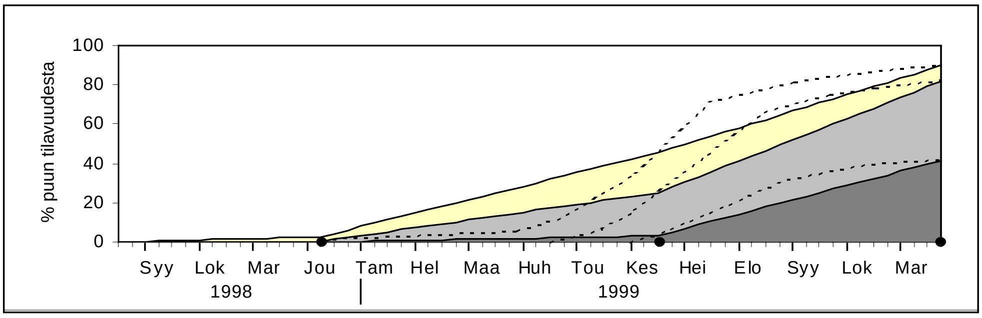
PÄRNU

February
1999



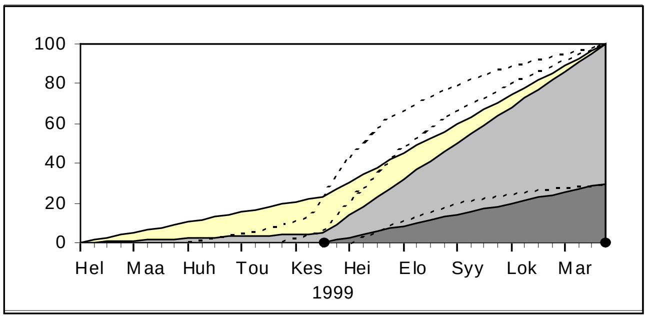
RIIKA

August
1998



RIIKA

February
1999

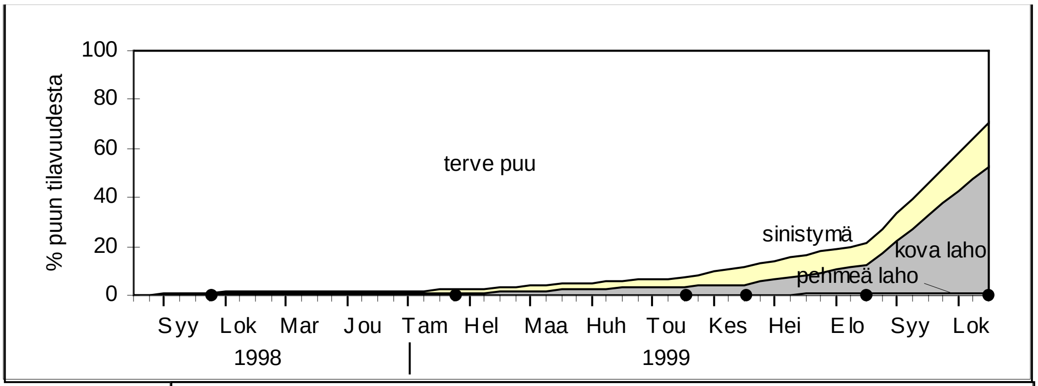


% puun tilavuudesta = % of billet volume

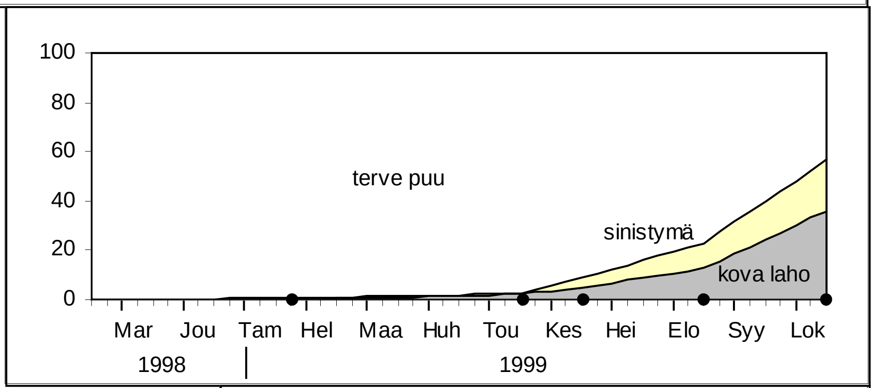
Figure 7. The spread of rot defect piles in piles of birch pulpwood felled in Estonia and Latvia in August of 1998 and in February of 1999. The time axis used in the figures starts from the felling time and the sampling times are shown on the axis. Due to the small number of sampling times, the paths of the graphs deviate from reality and the dashed lines are given to indicate the more probable paths.

SPRUCE **TILLOLA**

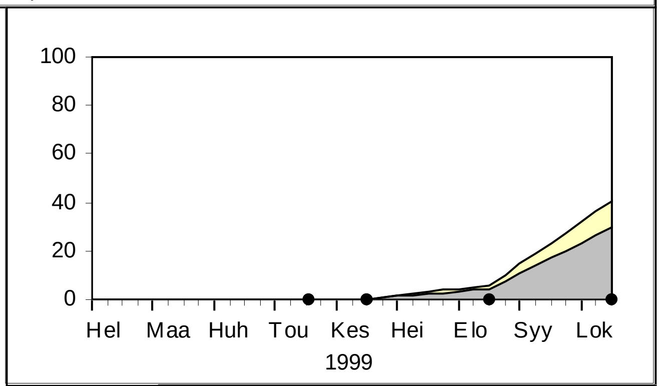
August 1998



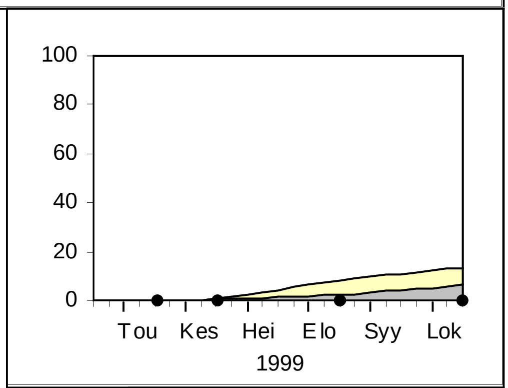
October 1998



February 1999



April 1999



terve puu = sound wood
sinistymä = blue stain
kova laho = hard rot
pehmeä laho = soft rot
sydänpuu = heartwood
terve mantopuu = sound sapwood
% puun tilavuudesta = % of billet volume

June 1999

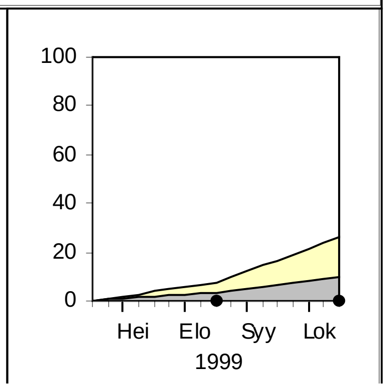
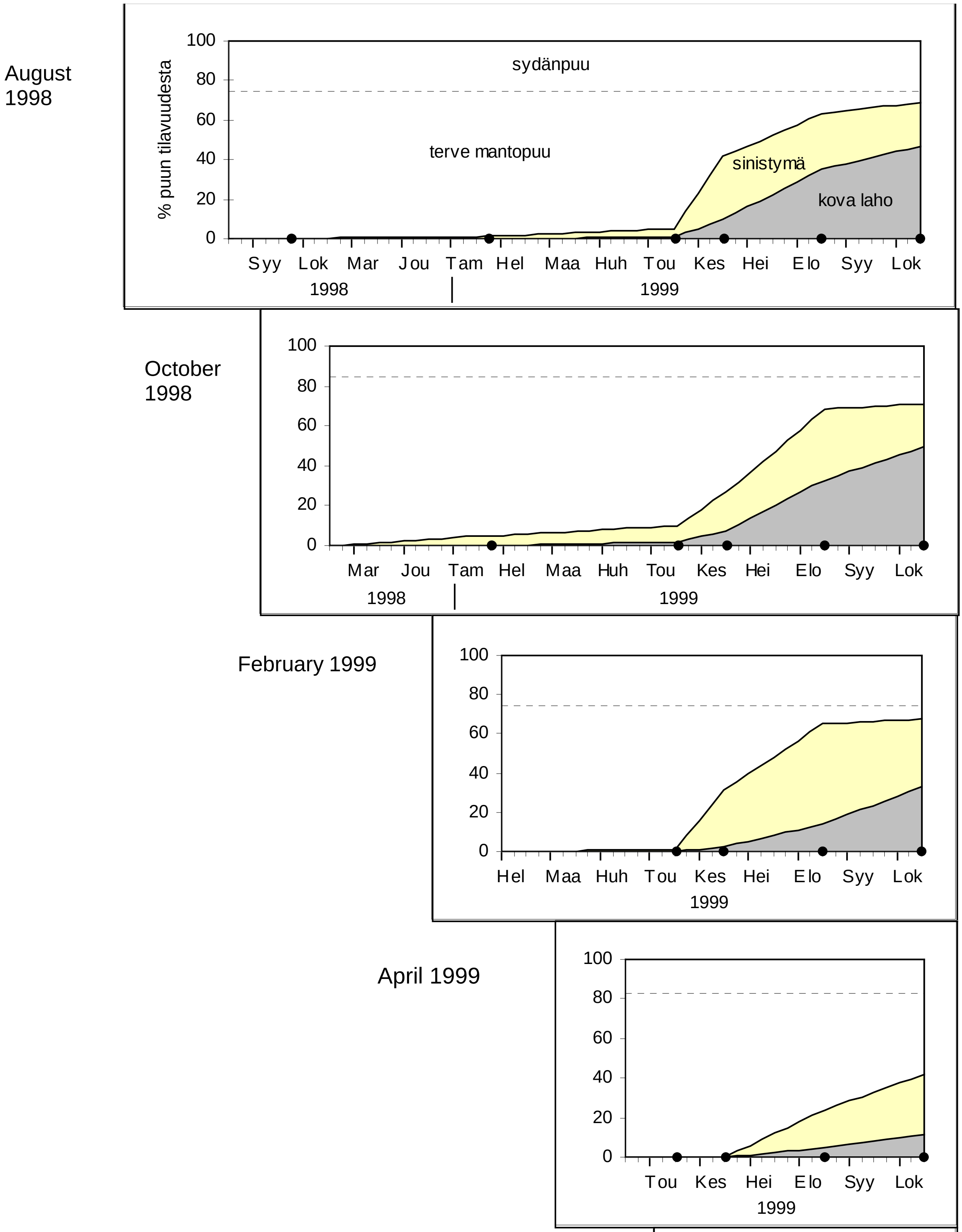
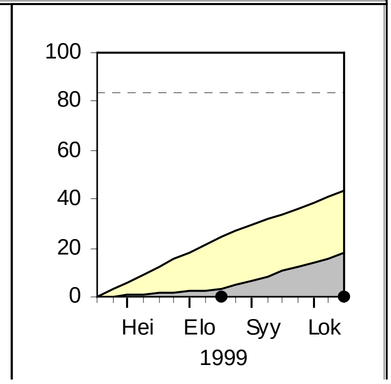


Figure 8. The spread of rot defect in piles of spruce pulpwood felled at different points in time. The time axes begin from the time of felling and the sampling times are marked on the axes.



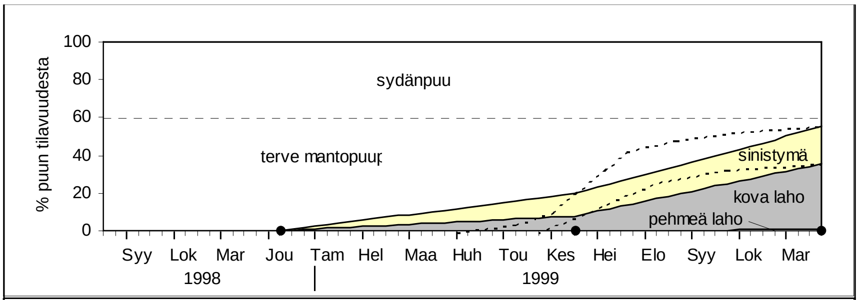


June 1999

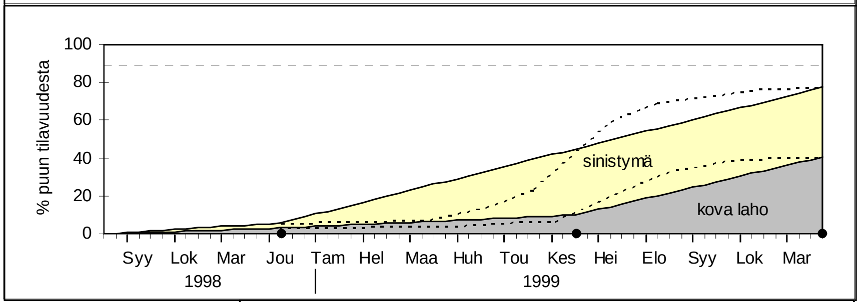
Figure 9. The spread of rot defect in piles of pine pulpwood felled at different points in time. The time axes begin from the time of felling and the sampling times are marked on the axes. The horizontal dashed line represents the boundary between heart-wood and sapwood in the average pulp-wood billet.

PINE

PÄRNU
August
1998



RIIKA
August
1998



PÄRNU
February
1999

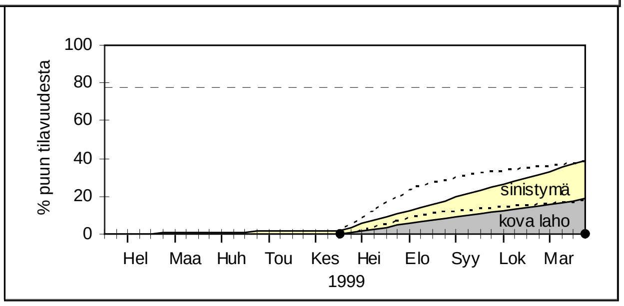


Figure 10. The spread of rot defect in pulpwood piles stored in Estonia and Latvia. The time axis used in the figures starts from the felling time and the sampling times are shown on the axis. Due to the small number of sampling times, the paths of the graphs deviate from reality. The dashed lines point out at the probable path of the graphs. The horizontal dashed line represents the boundary between heartwood and sapwood in the average billet.

3.2.5 Spreading of rot

Figs. 11 - 13 illustrate the spreading of the rot defect during the study period in average billets of birch, spruce and pine billets felled in August of 1998. Rot in autumn- and winter-felled birch pulpwood began to spread fast from the ends and more slowly from the sides of the billets (Fig. 11). Rot in spring- and summer-felled birch pulpwood began to spread fast also from the sides, apparently due to pronounced coming off of barking. In the case of pine and spruce billets, the rot spread from the ends and sides fairly evenly irrespective of the felling time (Figs. 12 and 13). The reason for this may have been in the dry and warm summer of 1999 which may have caused the rapid drying of the ends of pine and spruce billets and thereby hindered fungal growth on them.

However, bark damage failed to explain with statistical significance (p 0 < 05) the variation in the proportions of sound wood or decay for any of the pulpwood assortments.

BIRCH

pehmeä laho = soft rot
kova laho = hard rot
värivika = colour defect
terve mantop. = sound sapwood
sydänpuu (terv.) = heartwood (sound)

l/10 cm = litres per 10 cm

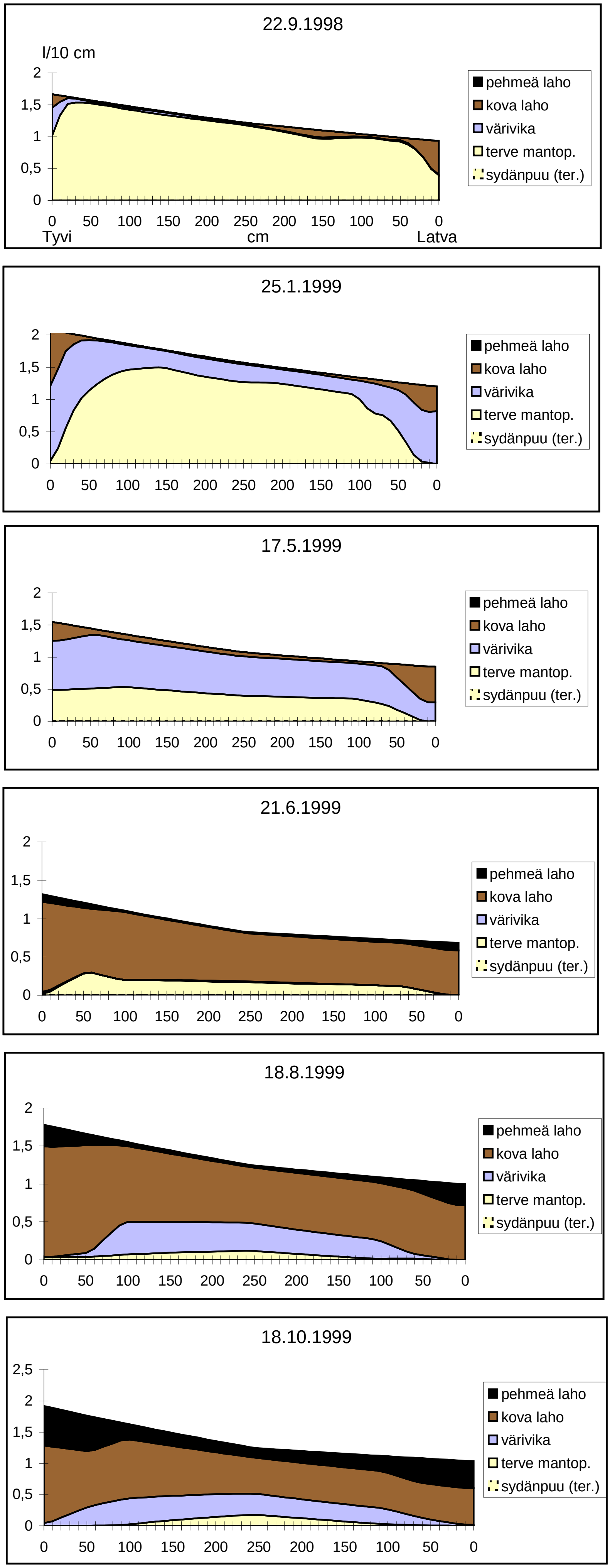


Figure 11. The spread of rot defects in a pile of birch pulpwood felled in August 1998. The horizontal axis shows the distance from the ends of the billet in centimetres and the vertical axis shows the volume in litres per 10 cm length of billet.

SPRUCE

pehmeä laho = soft rot
kova laho = hard rot
sinistymä = blue stain
terve mantop. = sound sapwood
sydänpuu (terv.) = heartwood (sound)

l/10 cm = litres per 10 cm

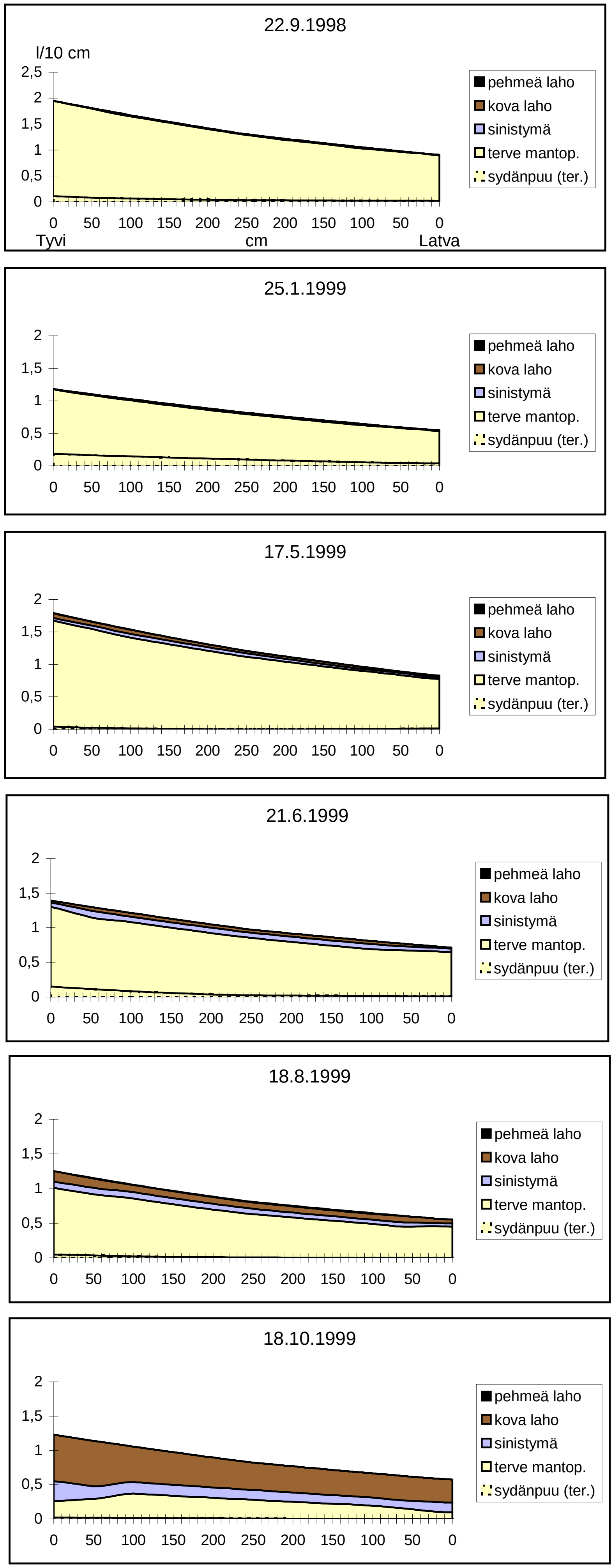


Figure 12. The spread of rot defects in a pile of spruce pulpwood felled in August 1998. The horizontal axis shows the distance from the ends of the billet in centimetres and the vertical axis shows the volume in litres per 10 cm length of billet.

PINE

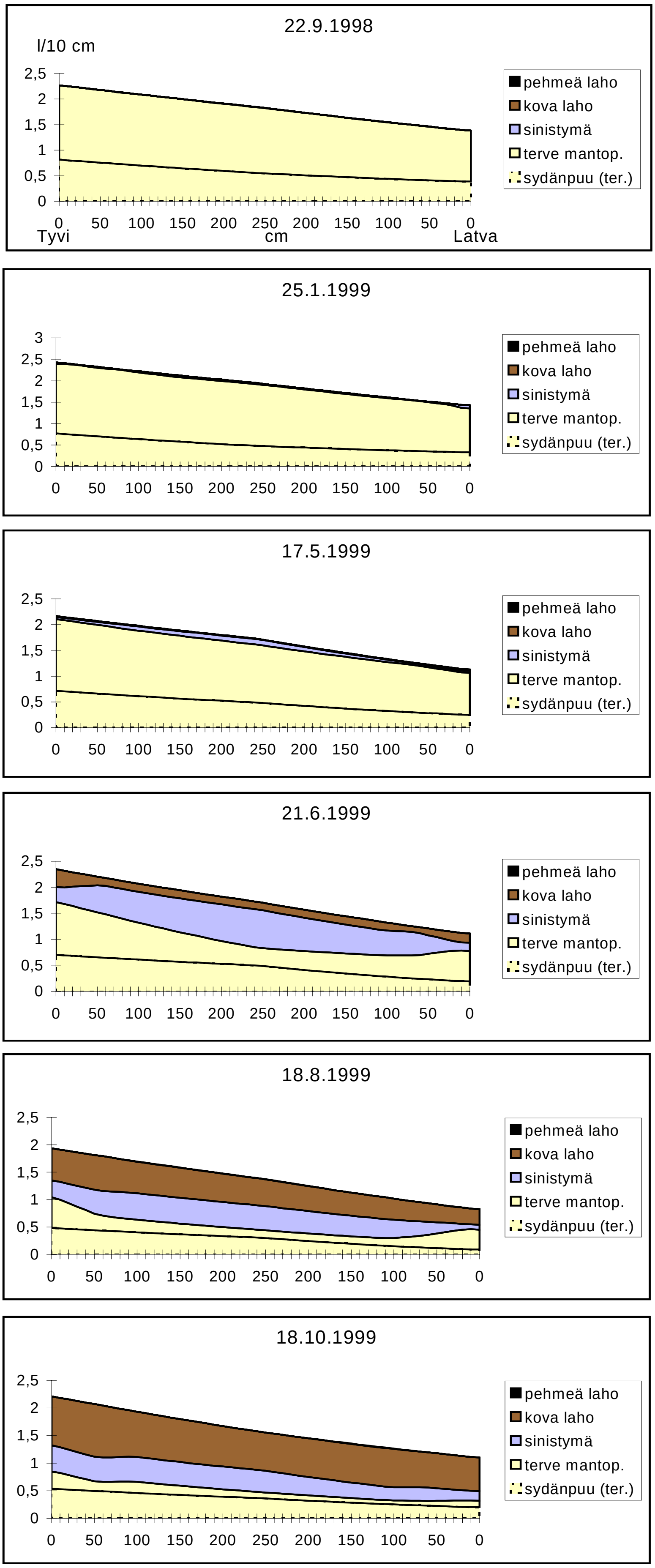


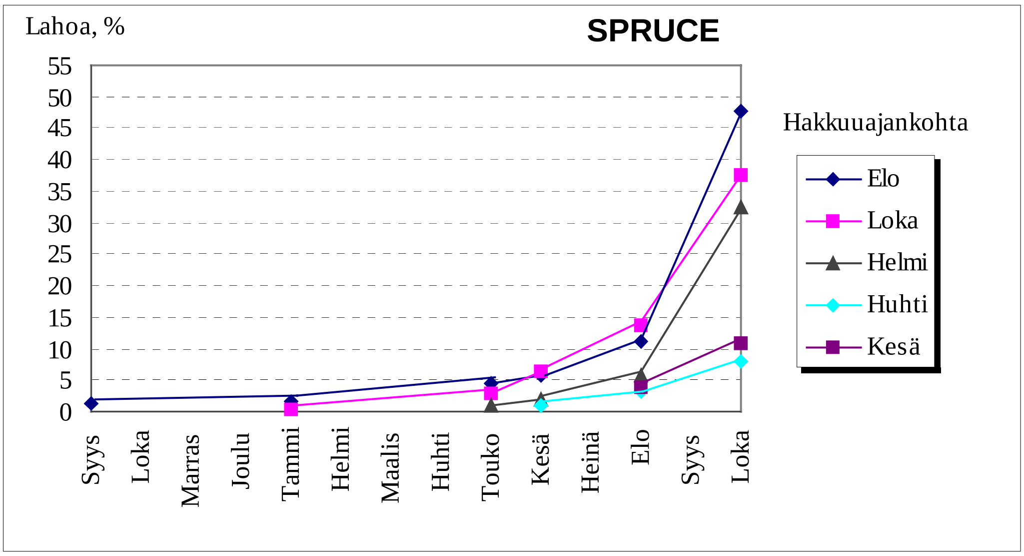
Figure 13. The spread of rot defects in a pile of pine pulpwood felled in August 1998. The horizontal axis shows the distance from the ends of the billet in centimetres and the vertical axis shows the volume in litres per 10 cm length of billet.

3.2.6 Factors affecting the degree of rotting in pulpwood stored in Finland

Felling time

The felling time and the length of the period of storage had more effect on the variation in the amount of rot than the other factors. The overall development of rot in spruce and pine pulpwood billets of the same size felled at various points in time and stored in Finland was computed using a model describing the material (Figs. 14 and 15). The corresponding figure for birch illustrates the amount of soft rot (Fig. 16).

The proportion of rot increased with increasing length of storage. The exceptions in the case of pine and spruce were the batches which had been felled before the onset of the trees' vital functions (in April), and these kept better than those felled later in June.



Lahoa, % = Proportion of rot, %
Hakkuuajakohta = Felling time
Time scale is from September 1998 to October 1999

Figure 14. Overall development of rot in spruce pulpwood felled at various points in time and stored in Finland (billet length 5 m, butt diameter 12 cm and top diameter 8 cm).

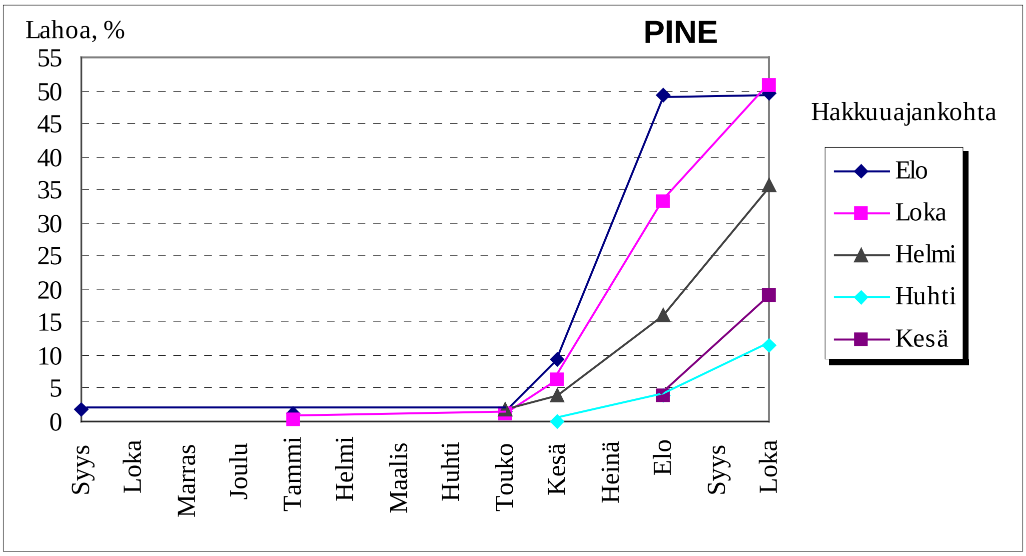
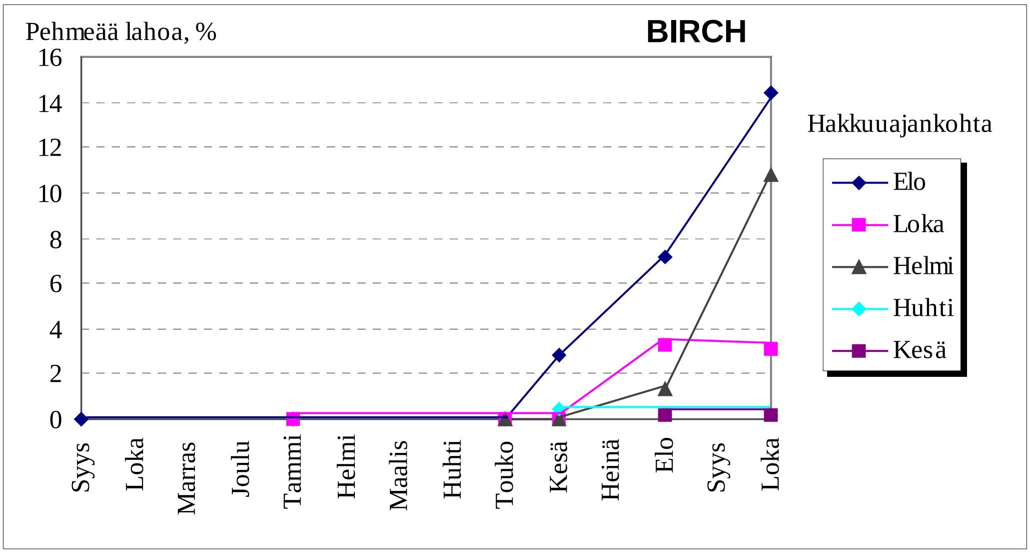


Figure 15. Overall development of rot in pine pulpwood felled at various points in time and stored in Finland (billet length 5 m, butt diameter 13 cm and top diameter 8 cm).



Pehmeää lahoa, % = Soft rot, %

Figure 16. Overall development of soft rot in birch pulpwood felled at various points in time and stored in Finland (billet length 5 m, butt diameter 11 cm and top diameter 8 cm).

Billet diameter

With pine and spruce billets, an increase in billet diameter was reflected as a decrease in the total amount of rot. A centimetre more in diameter reduced the rot percentage by 0.3% units. With birch, increasing diameter had the opposite effect.

Billet length

Billet length had the biggest effect on the amount of rot in spruce pulpwood. When billet length shortened by one metre, the rot percentage increased by 1.2% units. In the case of pine, the rot percentage increased by 0.7% units. Birch reacted differently as regards the effect of billet length, too. One metre less in length caused a decrease of 0.4% units in the amount of rot.

Billet taper

The taper of the billets was found to affect the amount of rot. Fast-tapering billets generally originate from the heavily-branched parts of tree stems; there was more rot in them than in others. The rot percentage in fast-tapering pine and spruce billets was higher than in others. The difference was greater in pine than in spruce. In the case of birch pulpwood, the variation attributable to taper was not consistent.

Moisture content and dry-green density weight

In the case of birch, billets containing a lot of sound wood were more moist and heavier than billets containing little sound wood. As regards the colour defect, the situation was the opposite; consequently, the spreading of the colour defect apparently required drying of the wood. The amount of hard rot did not provide a statistically significant explanation for the changes in the moisture content and dry-green density of the wood. An increase in soft rot significantly reduced both dry-green density and green density.

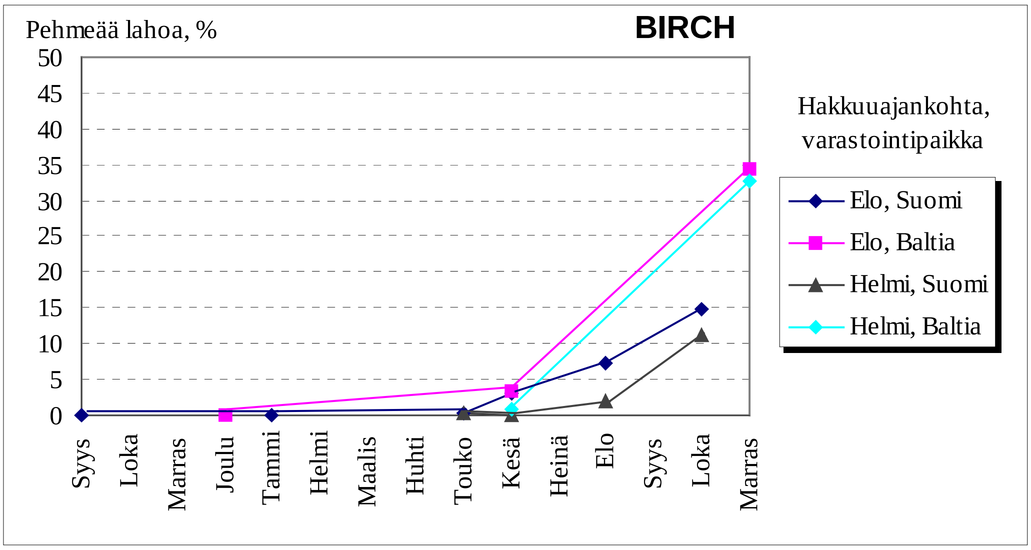
Contrary to birch pulpwood, pine and spruce billets containing a lot of sound wood were drier than billets containing little sound wood but a lot of wood spoiled by blue stain. Pine billets containing a lot of rot were more moist than billets containing little hard rot. It would appear that the drying of the pine and spruce billets during the dry and warm summer of 1999 progressed so well in the small piles stored in the open that the spread of fungal growth began to be restricted.

Pine billets containing a lot of sound wood had lower dry-green densities than those with a lot of blue stain. This result, contradictory as it may appear, was probably caused by variation in the amount of heartwood in the sample billets. The billets containing a lot of sound wood probably also contained a lot of heartwood with lower moisture content and lower dry-green density. Similarly, billets with a lot of blue stain had probably a high proportion of sapwood.

No correlation was observed to apply in spruce pulpwood between the amount of rot and the physical properties of the wood.

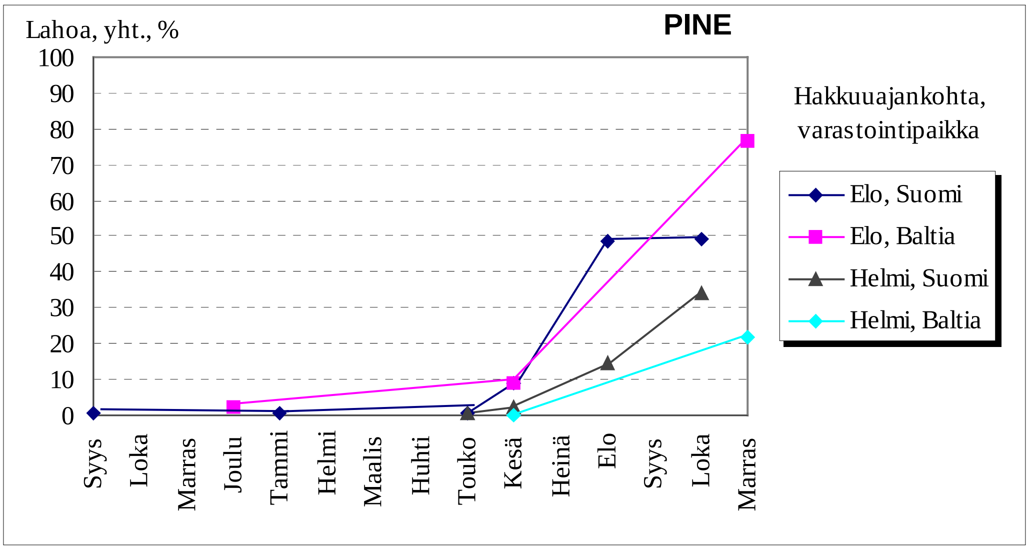
3.2.7 Spreading of rot in pulpwood stored in Finland and in Estonia and Latvia

The models based on collected material were used in determining the changes in piles of pulpwood in Finland and in Estonia and Latvia, comparable as regards their time of felling. In the case of birch, the amount of soft rot at the beginning of the summer was more or less at the same level in all three countries. Soft rot spread considerably faster during the summer and autumn in Estonia and Latvia when compared to Finland (Fig. 17). In the case of pine pulpwood, there was no consistent difference between the storage places in this respect (Fig. 18). The overall spread of rot in the winter-felled batches of pulpwood in Estonia and Latvia was slower than in Finland; in the case of the August-felled batches it was a little faster.



Pehmeää lahoa = Soft rot
Hakkuuajankohta, varastointipaikka = Felling time, storage location

Figure 17. The spread of soft rot in birch pulpwood felled in August of 1998 and in the winter of 1999 in Finland and in Estonia and Latvia. The real averages of the billets of the various felling batches were used in computing the rot percentages (Table 1, p. 14).



Lahoa yht. = Total proportion of rot

Figure 18. The overall spread of rot in pine pulpwood felled in August of 1998 and in the winter of 1999 in Finland and in Estonia and Latvia. The real averages of the billets of the various felling batches were used in computing the rot percentages (Table 1, p. 14).

3.3 Discussion

3.3.1 Rot: its causes and emergence

Decay of woody tissue is caused almost solely by fungi, especially bracket fungi and their close relatives. Fungal infection takes place by means of spores. Insects boring through the bark of the billets in the spring promote fungal infection during the summer, especially in the case of winter-felled pulpwood. Fungal hyphae spread fastest lengthwise in woody tissue (with the grain). Since infection by fungal spores is generally abundant, felled pulpwood normally becomes host to numerous fungal colonies, which in wood stored for a lengthy period of time are visible as radially oriented stripes.

Blue staining in pine and spruce caused by various moulds is usually the first sign of fungal infection (the term ‘moulds’ is used here to refer to fungi which do not decompose cellulose or lignin). The first brownish signs of actual decay appear soon after blue staining. Blue stain in birch wood is relatively rare. Birch typically develops a brown colour defect, which spreads in advance of a front of rot. We lack precise knowledge as to the cause of this colour defect; it may be caused by moulds, bacteria, or simply as a consequence of chemical changes when cells die. In this work only moulds (*Phialophora, Libertella, Trichoderma*, etc.) were isolated from birch wood with colour defects, or the sample cores were apparently not infected by fungi.

3.3.2 The role of moisture in the onset and spreading of rot

In addition to the ambient temperature, the moisture content of wood is among the foremost factors affecting the rate of rot in stored pulpwood. Decomposing fungi have clear limits in regard to wood moisture; if the wood is too moist, the fungi will not grow in it. Fungal growth is at its maximum when the moisture content of the wood is between 30% and 60%. The growth of fungi ceases once the wood has dried to 20% - 22% moisture content. It is only seldom that billets of pulpwood stored at the roadside become too dry for fungi, and certainly not in the inner and lower parts of piles.

The moisture content of the wood of live trees varies from one tree individual to the next and between different parts of the same tree. The formation of heartwood in conifers results in a considerable decline in the moisture content of the wood. The wood of young trees is usually more moist than that of old trees, which contain heartwood. Variation in the moisture content of the trunk of birches is more irregular than that observed in conifers, and the effect of tree age is not as clear. Moreover, the moisture content of the wood varies also according to the season of the year; it is generally at its highest in late winter and at it lowest in July-September (Nylinder and Rennerfelt 1954). Weather factors, mainly rainfall and temperature, cause short-term variation.

The sapwood of freshly-felled trees is too wet for most fungi. After being felled, trees begin to loose moisture from the cross-cutting surfaces and from places where the bark has been damaged, and it is through these that fungal hyphae are able to penetrate into the wood. The rate at which a billet of pulpwood dries depends on the weather factors, the extent of bark damage, billet diameter and billet length (Nylinder and Rennerfelt 1954). A sheath of intact bark protects the underlying wood from being infected by fungi and from losing moisture through evaporation.

Bark damage is at its minimum when trees are felled in winter and at its maximum in the summer. The damage to bark resulting from mechanised harvesting was not found to affect the spreading of storage rot in this study.

3.3.3 Spreading of rot

The birch pulpwood felled in August of 1998 in Finland was found to be spoiled by colour defect together with hard rot to an extent of about 35% by the autumn of the same year. The colour defect continued to spread rapidly during the following summer in this batch of birch and the batches felled in October and the following winter. Towards the end of June, 60 - 80% of the wood was spoiled by colour defect or hard rot. Part of the rot began to go soft from June onwards. The spreading of the colour defect was fast during the summer and early autumn also in birch pulpwood felled in April and June, but no soft rot was observed. In October there was only between 3%

and 7% of sound wood left. In Estonia and Latvia, soft rot spread through birch pulpwood faster than in Finland.

In pine pulpwood, the rot defect spread more slowly than in birch pulpwood. The hard rot in pine pulpwood felled in autumn and winter began to spread significantly after mid-June. At the end of the growing season, about half of the sapwood consisted of hard rot and most of the rest of sapwood had turned blue. No soft rot appeared during the first storage summer. Storage rot in pine stored in Estonia and Latvia spread at more or less the same rate.

The spreading of rot in spruce pulpwood during the summer was clearly slower than in pine and birch, although in pulpwood felled during the previous autumn and in winter it accelerated at the end of the summer. At the end of the growing season, hard rot amounted to 30% - 50%, while the figure for soft rot was less than 1%. In spruce pulpwood felled in April and June, hard rot during the first summer amounted, on average, to less than 10%.

3.3.4 Loss of wood raw material caused by storage rot

The results of this study regarding the effect of storage rot on the dry-green density of pulpwood may be looked upon as providing some guidelines: The fall in average dry-green density during the observation period of half a year varied between 0% and 6% in Finland and between 1% and 8% in Estonia and Latvia, depending on the pulpwood species.

These results are of the same order as those presented in studies conducted in Sweden. Björkman (1946) studied both debarked and un-debarked pine and spruce wood in which the predominant decomposing fungus was *Stereum sanguinolentum*, one of the foremost decomposers of conifer wood. The storage point was located in Southern Norrland, Sweden. The loss of dry matter after one year of storage varied within the range of 1 - 3%. After two years, the loss was about 5% and the loss in the yield of chemical pulp in trial cooks was approx. 10%. According to Henningsson (1973), the material loss of birch wood after one year of storage was approx. 3% in Northern Sweden, approx. 5% in Central Sweden, and approx. 10% in Southern Sweden. After two years of storage, the corresponding figures were approx. 5%, 9% and 17%, and after three years approx. 12%, 22% and 32%. Henningsson (1962) looked into the matter also in laboratory conditions under conditions optimal for rotting. After three months, the fall in dry-green density was 8% in birch billets, 1% in pine billets, and 0% in spruce billets. After seven months, the corresponding figures were 20%, 5% and 2%.

The results of the studies demonstrate quite consistently that the loss of woody tissue during the first summer is small in the case of coniferous pulpwood even though storage rot may already be quite visible. Most of the decomposing fungi in the initial stage of decay are white-rot fungi affecting both conifers and broadleaves, primarily destroying the lignin in woody tissue, although cellulose fibres also begin to gradually decompose (e.g. Henningsson 1962, 1967). It is only when the rot becomes soft that it causes significant losses in yield. On the basis of the results obtained in this study, soft rot begins to develop mainly in birch during the first summer of storage. The length and diameter of the billets were found to have a relatively minor effect on the amount of rot, and the degree of damage to the bark did not have a significant effect on the spreading of rot in the wood.

3.3.5 Comparison with the results of an earlier study

In connection with the earlier preliminary study, conducted two years earlier, stored birch pulpwood rotted distinctly more slowly than the pulpwood stored in Tillola during the summer of 1999 (Table 3). There were probably two reasons for this: (i) the birch batch in 1996 was felled a little later in the year than the August-felled batch in 1998, and (ii) the birch pulpwood in the earlier study were stored in large storage piles in the mill yard in Pietarsaari, whereas in this study the storage arrangements were small piles on a warm ridge along Salpausselkä. The differences between pine and spruce pulpwood were not as clear when comparing the results of these two studies. As regards the weather, the summers in 1997 and 1999 were fairly similar, above-average in warmth.

TABLE 3 The occurrence of rot defect during the summer following felling in comparable piles of pulpwood included in the previous study (Metsäteho Report 71, 1999) and in the present study. In the earlier study, the birch pulpwood was stored in Pietarsaari, while the pine and spruce pulpwood were stored mainly in Southern Finland.

Felling time	Rot defects during summer following felling					
	in June			in October		
	Blue stain	Hard rot	Soft rot	Blue stain	Hard rot	Soft rot
	Proportion, % of volume					
BIRCH						
August-September 1996 (Pietarsaari)	3	0	0	4	49	18
August 1998 (Tillola)	1	78	4	20	53	22
Winter 1997 (Pietarsaari)	2	0	0	38	32	0
Winter 1999 (Tillola)	50	19	0	10	63	13
PINE						
August-September 1996 (S-Finland)	24	3	0	27	39	2
August 1998 (Tillola)	32	10	0	22	47	0
Winter 1997 (S-Finland)	9	1	0	21	36	0
Winter 1999 (Tillola)	29	2	0	35	33	0
SPRUCE						
August-September 1996 (Valkeala)	4	11	0	12	29	5
August 1998 (Tillola)	7	4	0	18	52	0
Winter 1997 (Luumäki)	1	0	0	5	45	0
Winter 1999 (Tillola)	0	0	0	11	30	0

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