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Natural drying methods to promote fuel quality enhancement of small energywood stems

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Abstract

Due to fluctuating fossil fuel prices the use of forest biomass for energy is expected to increase considerably in the future. Today, the demand for high quality wood fuel products such as chopped firewood or pellets has increased price pressure on these products. In order to make the production more cost-effective new methods to optimize their production have to be found. Drying of raw material in the forest in order to improve the quality of the raw material and to reduce transportation costs can considerably improve the overall efficiency of the supply chain. It also enables longer storing periods and decreases GHG emissions and dry matter losses during storing.

The purpose of the study was to test natural drying and the effect of different degrees of partial debarking and different methods of bark scarifying as well as covering on natural drying of energywood stems. The test included laboratory tests in Finland and field trials in Finland, Scotland and Italy, using local practices and forest species commonly used as a raw material for different forest energy products.

In the laboratory test for birch, partial debarking and scarifying can be as effective drying accelerants as traditional splitting. It is important that scarifying is done all over the stem. During the test, untreated stems were drying from original 48% of moisture down to 35% during 6 months of drying between March and September. During the same period, split, partially debarked and scarified stems achieved more than 10%-units lover moisture. With pine, scarifying does not work as effectively with small percentages of removed or scarified bark.

According to the results of the field trials, the debarking using a harvester head had a significant effect on moisture content decrease during the drying season especially when the stacks were covered. Covering is more vital in rainier circumstanses, but nevertheless there are also notable differences between tree species. The results show that the tested broad-leaved trees, *(Petula pubescens),* alder *(Alnus incana)* and sitka spruce (*Picea sitchensis)* dry faster than pine *(Pinus sylvestris)* and lodge pole pine *(Pinus contorta)*.

The results showed that debarking using, e.g. a harvester head, can be quite demanding due to different characteristics of tree species and diameters. The debarking device should be designed so that it could be switched on only when needed. This would ensure that the harvester head could be used to harvest normal timber and also energy wood.

In conclusion, the drying season is essential to decrease the moisture content particularly in Finland and Scotland. The results show that the moisture content can be decreased by 15–20% in several months using only solar and wind power if more bark than normal is removed and the piles are covered.

Keywords

wood-fuel logistics, moisture content, natural drying

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Contents

Part 1

Partial debarking of stemwood as part of the chain of production of forest chips and split firewood

Ari Erkkilä, Antti Heikkinen, Heikki Kaipainen, Kari Hillebrand and Heikki Oravainen

1 Introduction

For small chip-fired heating plants to run with minimum of disturbances the fuel chips should be preferably made from stemwood and the chips should not be very moist. Indeed, a frequent problem affecting small chip-fired heating plants is the excessive moisture level of the fuel. This problem is emphasised especially in rainy regions such as England and Scotland. The moisture in wood offers excellent conditions for the growth of various moulds and decay-causing fungi. This adds to the losses in dry matter during storage, impairs the quality of the fuel, and increases the health risks associated with mould dust. The energy density calculated per moist wood mass and volume is lower than those of dry wood. The drier fuel chips are, the better the coefficient of efficiency and cleanliness of the actual combustion. Pre-dried logwood can be used to produce stemwood chips of high-quality and uniform quality, and in suitable applications these chips can be sold for a better price than chips made from logging residue and whole trees.

The costs of transportation are also significantly reduced if energy wood is allowed to dry. In Britain and in most parts of continental Europe, effective loads are often limited to 20 tonnes because of strict weight limits whereas in Finland loads can be as much as 40 tonnes. Due to the low effective load, it is uneconomical to transport the water contained in wood as part of the available load volume remains unused, whereas in Finland it is the volume of the load space when carrying energy wood which is usually the restricting factor. Furthermore, stemwood is available is in the aforementioned countries as raw material for energy-wood more often than is the case in Finland because the following reasons: the minimum top diameters for pulpwood are higher than in Finland; there is not always commercial demand for pulpwood-sized roundwood due to the tree species or the long distances to mills; the small proportion of regeneration cuttings; and environment-related restrictions imposed limits on the energy use of logging residue.

Drying the wood results in a significant cost and is one of the hindering factor in the production of split firewood, and therefore the advantages of dried raw material are significant also in the firewood production process. Indeed, one interesting item of development when aiming to improve the efficiency of the splitting capacity is the partial peeling and natural drying of logwood and cross-cutting logwood in bundles. Cross-cutting in bundles is advantageous for the reason that when using conventional firewood processors, and even when the raw material is dry, small-diameter logwood is a problem, and it reduces the productivity of splitting. Wood of less than 10 cm in diameter does not need to be split if it has been possible to dry the wood close to the usage moisture level during the storage phase.

The drying of large stems, which have been sorted according to diameter, can be accelerated by splitting the wood as drying is also possible via the split surface. The traditional practice with firewood has been to dry the wood as split pieces. The split and dried semi-finished product enables new opportunities in the split firewood business models.

Nowadays, strip-debarking of logwood is, however, a separate work stage; e.g. it is done using a debarking machine modified to imitate traditional strip-debarking done using hand tools. Debarking done in connection with cutting enables lower costs and drying commences immediately. In certain conditions, a harvester may be used for debarking the logs already in connection with cutting. This method is widely used when harvesting eucalyptus because once eucalyptus dries it becomes very difficult to get a good debarking result. However, a harvester heads equipped with debarking feed rollers, a.k.a. euca-rollers, are not suitable as such for debarking the tree species found in Finland because debarking would require running the log back and forth 2–3 times. This further reduces the already low productivity when dealing with small-diameter trees.

Trials with structurally-modified strip-debarking harvester heads have also been conducted in Finland. Pieces of metal were welded onto the delimbing blades to cause strips of bark to come off and the effect of this on drying was then studied. The results showed that the debarking must be more efficient for acceptable drying to be achieved. The metal pieces were found to just scratch the bark and the amount of bark removed was twice that of normal harvester-based logging. However, the debarking percentage remained low (about 12%), and consequently further work on modifying the blades is necessary. The debarking method should be suitable for dealing with tree species such as birch, Scots pine and Lodgepole pine so that the outcome of debarking would considerably accelerate the drying of the wood and improve the quality of energy chips.

This study was conducted to seek out efficient treatments that would promote the drying of logwood, to verify the results obtained by means of drying tests, to determine suitable chains of production, and to assess the pros and cons of partial debarking.

2 Objective

The objective of the project was to improve the quality of the raw material of forest chips and split firewood and the effectiveness by the production chains by studying and developing the debarking of stemwood in harvester-based logging and the drying and multiple-cutting of strip-debarked logwood and tied bundles of logwood.

The debarking method to be developed had to be both suitable for dealing with the debarking of tree species such as birch, Scots pine and Lodgepole pine and considerably accelerate the drying of the wood thereby improving the overall quality of energy chips.

3 Effect of treatments on the drying of logwood in the chain of production of split firewood

3.1 Drying of individual logwood lengths in laboratory tests

3.1.1 Test arrangements in the laboratory

The effect of removing and scratching the bark on drying was studied at VTT's Jyväskylä unit using a condition simulator and a heating chamber. The heating chamber enabled the simultaneous drying of several pieces of wood subjected to different treatments, but the conditions were not as controlled as the conditions in the condition simulator. Based on the results of the heating chamber trials, some of the treatment alternatives were selected for a more detailed study in the condition simulator. The results were used to select the treatments for the subsequent drying trials done with bundles of logwood in natural conditions.

The set-point value applied in the heating chamber was 25°C. The moisture level inside the chamber could not be regulated separately; instead, it was determined based on the moisture evaporating from the test pieces and the ventilation of the heating chamber. During the tests the temperature was within the range 25°C–29°C and the relative humidity of the air was within the range of 20%–60%. The temperature of the air inside the chamber rose during the test while the relative humidity dropped. During the tests, the ventilation of the heating chamber was set to its highest level. In order to even out conditions, a blower was used for recycling the air inside the chamber. In addition, the location of the test pieces in the chamber was varied in conjunction with weighing them. Perforated steel shelves were used as drying platforms in the heating chamber.

The condition simulator had standard conditions for drying. The temperature was 25°C, the relative humidity of the air was 40%, and wind speed was 1 m/s. Rain and heat radiation were not used in the tests. The substrate was asphalt. There were metal pipes arranged underneath the pieces of wood to keep them off the asphalt.

The tests were conducted with pieces of birch and pine wood. The length of 90 cm of the test pieces was set to comply with the inside dimensions of the heating chamber and the condition simulator. The nominal diameters of the pieces of wood were set at 8 cm and 16 cm. The 8 cm test pieces were stems of 7–9 cm in diameter while the 16 cm test pieces were 15–17 cm in diameter. The ends of the test pieces were painted to prevent drying through the ends because the purpose was to study the effect of breaking up of the bark. Where possible, multiple pieces of wood treated in the same way were used in the tests.

The bark treatments were implemented manually. The debarking was done using a knife. A ruler was used as an aid when debarking. The boundaries of the debarking were cut using a knife and this was followed by removing the bark and the underlying phloem layer with a chisel. The slashes (a small cut) were made using a knife and scratches were made using a hard-metal spike. The slashes did not cause woody tissue to be exposed. Scratches caused the bark to break up along a width of 2–3 millimetres. The splitting work was done mainly using a band saw, but drying of split wood was also compared by having pieces split with an axe. The tests also included pieces of wood with grooves cut into them using a circular saw. The trace left by a harvester head equipped with feed rollers was emulated using a tubular chisel to break the bark on two sides of the piece of wood. The treatment was fairly light. Figure 1 shows test pieces treated in different ways and Table 1 shows the proportion of removed bark in the various treatments. The drying process was monitored by weighing the pieces of wood once a day at the beginning of the drying period after which the intervals between weightings were extended as the drying slowed down. At the end of the trial, final moisture samples were taken from the pieces of wood providing the basis for drawing up the final drying graphs. All tests including split wood were made using a band-saw, and the drying of such pieces enabled comparison with pieces representing different treatment and it was possible to monitor that the conditions remained as originally intended.

Figure 1. Differently treated test pieces of wood. Uppermost, slashed and scratched; middle 1 cm and 2 cm strip-debarking; and lowermost split and fully debarked. © Antti Heikkinen and Ari Erkkilä.

Table 1. Proportions of bark broke up or removed of the outer perimeter of the pieces of wood in the different treatments for wood 8 cm in diameter. (In split wood, proportion of split surface area.)

Treatment	Number of pieces	Proportion of broken-up or removed bark, %
Slashes		0
Scratch, 2mm	4	3
Scratch, 2mm	8	6
Strip-debarking, 1cm	2	8
Strip-debarking, 1cm	4	16
Strip-debarking, 2cm	2	16
Strip-debarking, 2cm	4	32
Split		32
Debarked		100

3.1.2 Results and their assessment

The results are presented as graphs showing the drying and drying times of the test pieces and as relative drying times compared to the drying of the split wood included in each test. The initial moisture levels of the test pieces were not always exactly the same. Due to this, we aimed to improve the comparability by examining the drying times when the moisture level dropped from 40% to 20%. The drying times of the test pieces, which dried the slowest, were obtained by extrapolating using the straight line passing through the last and the third-last observation point along the drying graphs. The drying times obtained are approximate values. The differences in the diameters of the test pieces were taken into account by proportioning the drying times according to the diameter of the piece of split wood in each test in compliance with the calculated cross-sectional area.

Heating chamber tests, birch

In the first test, the effect of strip-debarking on drying was studied compared to the drying of pieces of non-debarked, fully-debarked and split wood. The drying results of this test are shown in Figure 2 and Table 2. The effect of the degree of strip-debarking on drying was studied compared to the drying of pieces of non-debarked, fully-debarked and split wood. Non-debarked wood was slow to dry whereas split wood and fully-debarked wood dried from the initial moisture to 20% moisture within 11 and 14 days. Strip-debarking treatment (4 strips at 2 cm each) caused the test pieces to dry to 20% moisture in 16 days. As the width of strip-debarking and the number of strips increased, drying accelerated. Doubling the number of strip-debarking strips from two to four was a better method than doubling the strip width from 1 cm to 2 cm.

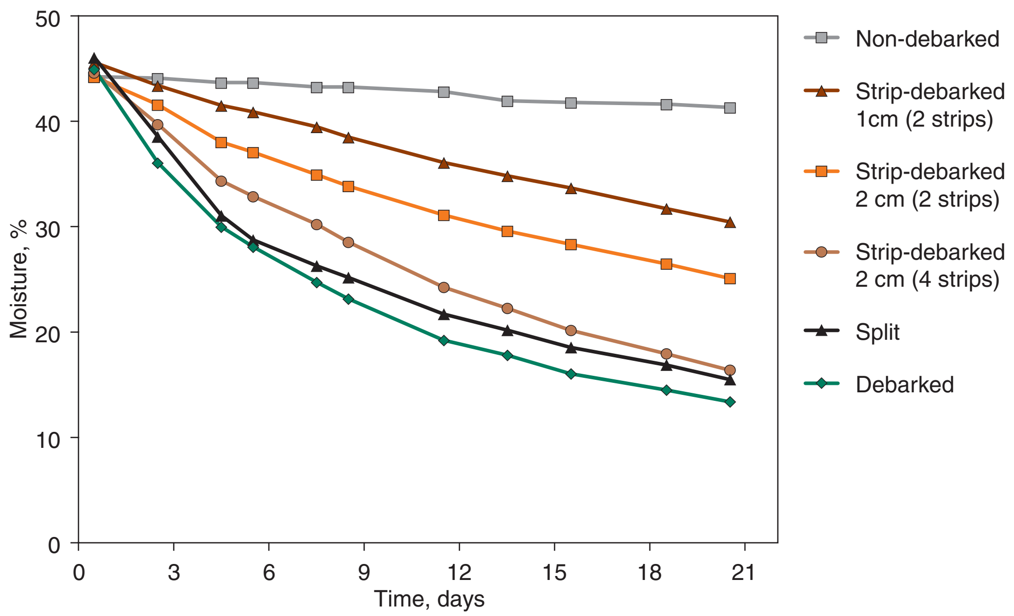

Figure 2. Drying of birch logwood in the heating chamber (Test 1). The effect of degree of strip-debarking on drying was studied compared to the drying of pieces of non-debarked, fully-debarked and split wood.

Table 2. Drying time of test pieces of wood within the moisture level range of 40%–20% and the relative drying time when compared to pieces of split wood (Test 1). The diameter used in calculating the relative drying time was 7.8 cm.

Treatment	Measured drying time 40%–20%, days (@ 24h)	Calculated relative drying time, %
Debarked	10	73
Split	13	100
Strip-debarking, 2cm/4x	14	119
Strip-debarking, 2cm/2x	- [1)]	>210
Strip-debarking, 1cm/2x	- [1)]	>215

[1)] The moisture level did not fall to 20% during the test

The purpose in Test 3 was to study the accelerating of drying by breaking up the bark of pieces of birch wood by means other than strip-debarking. The bark treatment was implemented at equal intervals along the perimeter of the piece of wood and it had the effect of shortening the distance to be travelled by water from inside the wood to the evaporation zone. The test also investigated whether it is possible to further accelerate the drying of split wood with the help of bark treatment. The results are shown in Figures 3 and 4 and Table 3. It was observed in this test that split wood dries the quickest, especially at the beginning of the drying period, but also that pieces of wood with eight scratches and slashes and four grooves dried well (Figure 3 and 4). In terms of the drying rate, the results showed a groove extending 10 mm into the wood is better than removing a strip of bark equal in width to the depth of the groove. However, the loss of dry matter when sawing the grooves is greater than in strip-debarking. Sufficient bark treatment is needed around the piece of wood, since the outcome of four scratches and slashes was clearly inferior. Approximately the same effect was achieved with a single groove 3 mm in width and extending to the centre of the piece of wood (Figure 4). The drying of split wood was accelerated further when the remaining bark was broken up. The time required for drying of split wood was shortened by almost 50% as a result of strip-debarking and as a result of a single slash and scratch implemented on the remaining bark (Figure 4). The drying time was further shortened when more bark was removed. Wood that had been split and then strip-debarked (3x1cm) dried equally well as wood that has been split and fully debarked. The drying time of wood split in Test 1 averaged 13 days and it was shorter than in Test 3 in which the drying time was 19 days. This was caused by differences in the diameters of the pieces of wood. The average diameter of the split pieces of woods in Test 1 was 7.8 cm and Test 3 it was 9.0 cm.

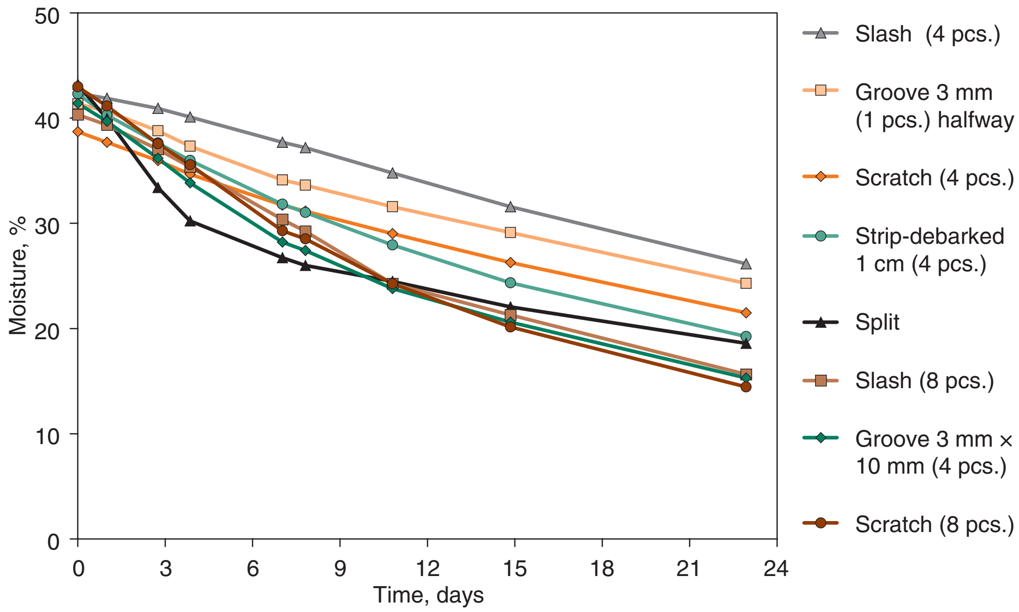

Figure 3. Drying of birch logwood in the heating chamber following different treatments (Test 3).

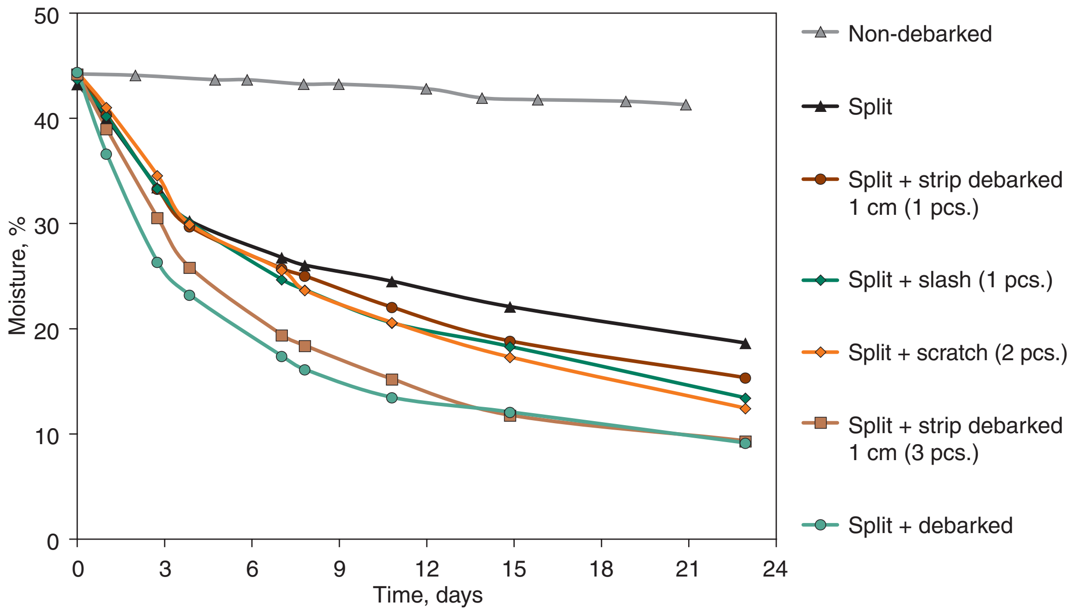

Figure 4. Acceleration in the drying of split birch logwood following further treatments (Test 3).

Table 3. Drying time of test pieces of wood within the moisture level range of 40%–20% and the relative drying time when compared to pieces of split wood (Test 3). The diameter used in calculating the relative drying time was 9.0 cm.

Treatment	Measured drying time 40%–20%, days	Calculated relative drying time, %
Splitting	19	100
Groove 3mm*10mm, 4x	15	111
Scratch, 8x	13	116
Slash, 8x	17	126
Strip-debarking, 1cm/4x	21	132
Scratch, 4x	- [1)]	>190
Slash, 4x	- [1)]	>200
Groove 3 mm to centre, 1x	- [1)]	>215
Split + strip-debarking, 1cm/3x	6	32
Split + debarking	6	32
Split + strip-debarking, 1cm/1x	12	58
Split + scratch, 1x	11	63
Split + slash, 1x	11	63
Split	19	100

[1)] The moisture level did not fall to 20% during the test

Pieces of birch wood with a 16 cm diameter were also dried in the heating chamber. The drying results are shown in Figure 5 and Table 4. The doubling in diameter increased the drying time of split wood 2.5-fold. The results also indicated that the relative drying time of strip-debarked wood increased compared to split wood with increasing diameter of the test pieces (Figure 2). The results show that the number of strip-debarking strips should be increased as the diameter increases to reach a similar drying rate compared to drying of split wood. Increasing the width of strip-debarking from 1 cm to 2 cm did not accelerate the rate of drying.

Table 4. Drying time of test pieces of wood within the moisture level range of 40%–20% and the relative drying time when compared to pieces of split wood. The diameter of the pieces of birch wood was 15.7 cm.

Treatment	Calculated drying time 40%–20%, days	Calculated relative drying time, %
Split	approx. 32	100
Strip-debarking, 2cm/4x	> 45[1)]	>140
Strip-debarking, 1cm/4x	> 45[1)]	>140

[1)] The moisture level did not fall to 20% during the test

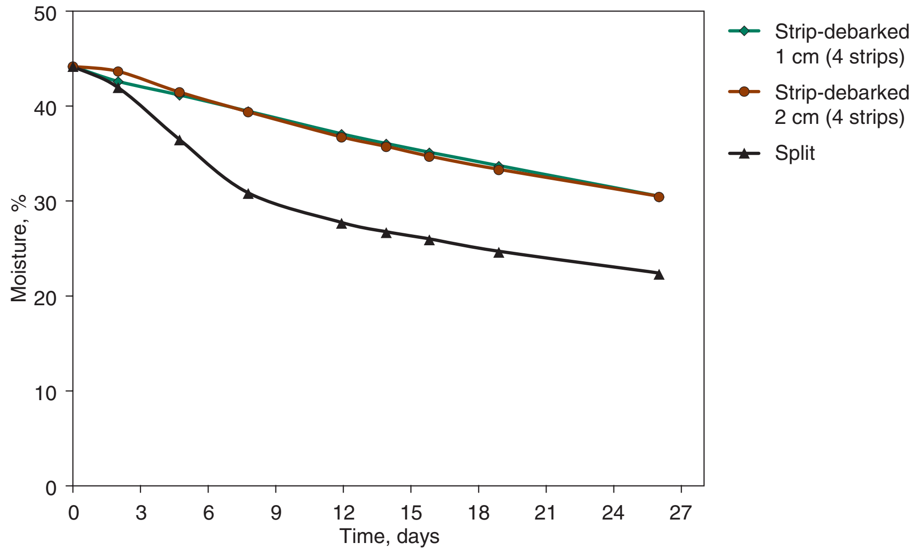

Figure 5. Drying of pieces of birch wood 16 cm in diameter in the heating chamber.

Condition simulator trial, Birch

The drying conditions in the condition simulator were kept maintained during the entire drying period. The results of drying (Test 2) are presented in Figure 6. The effect of the strip-debarking degree on drying was studied compared to the drying of pieces of non-debarked, fully-debarked and split wood.

The drying time of fully debarked wood was less than 80% of the drying time of split wood. The effect of strip-debarking was in line with the heating chamber trials. The relative drying time of wood with strip-debarking implemented on four sides was about 10% longer than the drying time of split wood. The drying time of wood treated with strip-debarking on two sides was over double that of the drying of split wood. The effect of a groove to accelerate the drying was less than that of strip-debarking.

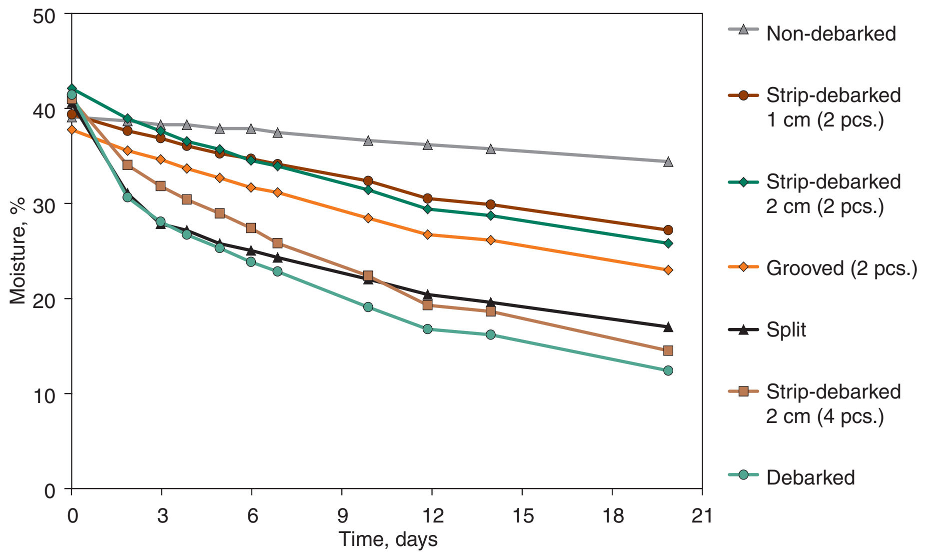

Figure 6. Drying of birch logwood in the condition simulator (Test 2).

Table 5. Drying time of test pieces of wood within the moisture level range of 40%–20% and the relative drying time when compared to pieces of split wood (Test 2). The diameter used in calculating the relative drying time was 8.7 cm.

Treatment	Measured drying time 40%–20%, days	Calculated relative drying time, %
Debarked	9	77
Split	13	100
Strip-debarking, 2cm/4x	11	108
Strip-debarking, 2cm/2x	- 1)	>230
Strip-debarking, 1cm/2x	- 1)	>260
Groove 3 mm*10 mm, 2x	- 1)	>340

1) The moisture level did not fall to 20% during the test

Test 4 was conducted to look into the effects of slashes and scratches on drying compared to pieces of wood split either using an axe or a band saw. The diameters of the pieces of wood used in the trial were larger than in earlier trials. The results are presented in Figure 7 and Table 6. Wood split using an axe dried about 25% faster than wood split using a band saw. A more uneven and splintery surface is created when splitting with an axe, and therefore there is a greater surface area available for evaporation than is the case when sawing. In the condition simulator trial, eight scratches produced even better results than in the heating chamber trials. The relative drying time (94%) was even a little shorter than the drying time of split wood. The drying time of the slashed pieces of wood was about 20% longer than that of pieces split using a band saw. The breaking up of the bark using a chisel and emulating the result of passing a piece of wood through a roller-fed felling head almost doubled the drying time compared to the time it took for split wood to dry.

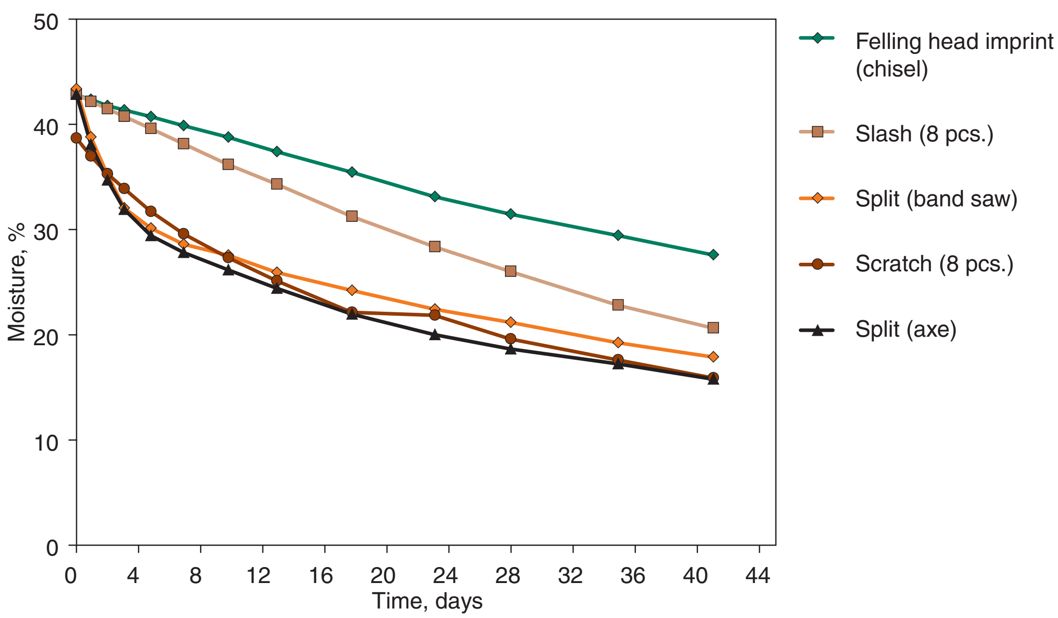

Figure 7. Drying of birch logwood in the condition simulator (Test 4).

Table 6. Drying time of test pieces of wood within the moisture level range of 40%–20% and the relative drying time when compared to pieces of split wood (Test 4). The diameter used in calculating the relative drying time was 9.8 cm.

Treatment	Measured drying time 40%–20%, days	Calculated relative drying time, %
Split using an axe	22	74
Scratch, 8x	28	94
Split using a band saw	31	100
Slash, 8x	36	122
Processor marks emulated using a chisel	- [1)]	>200

[1)] The moisture level did not fall to 20% during the test

Condition simulator trial, Pine

Test 5 involved drying pieces of pine wood in the condition simulator. The results are presented in Figure 8 and Table 7. The results differed from those of tests done with birch. Due to the higher initial moisture level of pine, the moisture level interval for observing drying of 40%–20% occurs further away from the beginning of the test, and this can impair the comparison with the drying of birch wood. Debarked and split wood dried considerably faster than birch despite the higher initial moisture of the pieces of wood. Heavy strip-debarking (4x2cm) accelerated the drying of pine, but not as much in relation to the rate of drying of split wood as did the corresponding treatment on birch. Lesser degrees of bark treatment resulted in considerably slower drying. An increase in the number of scratches to 8 was not enough to accelerate the drying of pine as much as it did with birch.

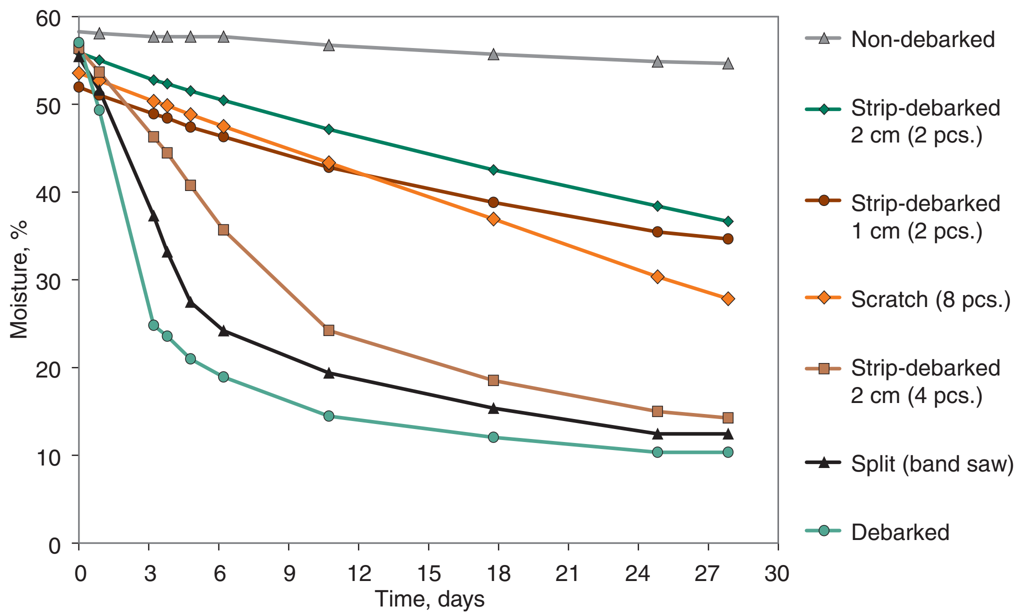

Figure 8. Drying of pine logwood in the condition simulator in Test 5.

Table 7. Drying time of test pieces of wood within the moisture level range of 40%–20% and the relative drying time when compared to pieces of split wood (Test 5). The diameter used in calculating the relative drying time was 8.5 cm.

Treatment	Measured drying time 40%–20%, days	Calculated relative drying time, %
Debarked	3	38
Split (using a band saw)	7	100
Strip-debarking, 2 cm/4x	11	148
Scratch, 8x	- [1)]	>330
Strip-debarking, 2 cm/2x	- [1)]	>470
Strip-debarking, 1cm/2x	- [1)]	>640

[1)] The moisture level did not fall to 20% during the test

3.2 Drying of logwood bundles outdoors

3.2.1 Test arrangement

The bundle drying tests were conducted in Rautalampi during the spring and summer of 2007. The tree species was birch and varied within the range of 7–15 cm. The bundle length was set at 2.6 m for all bundles. The chosen treatments were splitting, strip-debarking, scratching and untreated. The treatments and bundling were carried out on the 28–29.3.2007. Some of the trees had been felled a few days earlier and the rest were felled just before bundling. The trees were felled and delimbed by forest workers and thus it was possible to avoid bark damage. The splitting was done using a portable circular saw. Logwood less than 15 cm in diameter were split into two while bigger pieces were split into four pieces (Figure 9). The share of exposed wood surface averaged 44%. The scratches in the bark were made using a self-made hook-like blade shown in Figure 10 and 11. The scratches were made around the piece of wood as evenly as possible. The share of the surface broken-up by the scratches was on average 5%. In practice, the woody tissue was not exposed.

The strip-debarking was done using a chainsaw and an auxiliary device called Kuorija 300, which is normally used for debarking logs. This strip-debarking differed from the laboratory tests done at VTT in that the strips were wider, 2–5 cm. Kuorija 300 was an efficient tool and along with the bark it also removed some woody tissue. Strip-debarking was done on 2–4 sides depending on the size of the piece of wood. The share of the broken-up or removed bark was approximately 26%. On average, 12% of the woody tissue was exposed. Strip-debarked pieces of wood are shown in Figure 12.

Figure 9. Bundles made from split pieces of logwood. © Ismo Tiihonen.

Figure 10. The blade used for implementing the scratches. © Antti Heikkinen.

Figure 11. Scratches in the bark of a piece of birch logwood. © Antti Heikkinen.

Figure 12. Strip-debarked pieces of birch. © Antti Heikkinen.

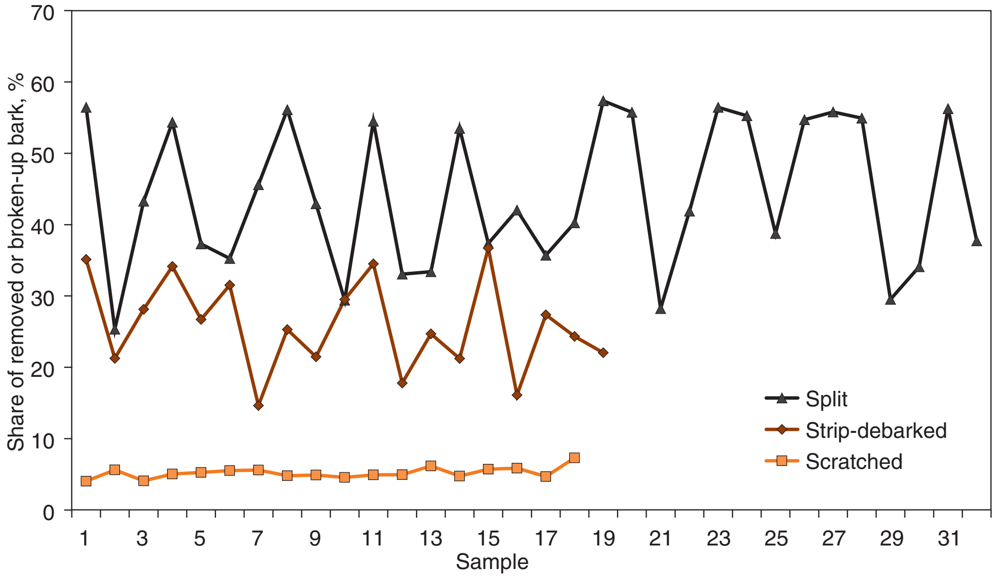

Figure 13. Share of removed or broken-up bark in the sample pieces of short-cut split firewood.

Bundling was done by collecting the pieces of logwood within a metal frame. Inside the frame, the bundles were formed using light load-binding straps. The straps were 35 mm in width. The bundles were 70 cm in diameter. Three bundles were made of strip-debarked, scratched and split wood each. Three bundles were untreated logwood. In addition, the pile included filling-in bundles made using the whole-tree baling device developed by Pasi Romo of Biotukki Oy. It was avoided to place the monitoring bundles in the top or the bottom layer in order to minimise the edge effect.

The monitoring of the drying process was based on weighing the bundles. The starting and ending weightings were done using a hook scale. The interim weightings were done using a pump cart equipped with scales. The bundles were weighed in the spring at intervals of 1–2 weeks and in the late summer at intervals of 1 month. Moisture samples were taken from the bundles on 8.8.2007, after which the drying graphs were drawn based on the moisture results and weighing results. When the monitoring ended, samples were also taken on 23.10.2008 and the moisture levels of these samples corresponded well with the moisture levels that had been calculated using the samples taken in August. The pile was covered for the duration of the drying using WalkiWisa Oy’s covering paper (Figure 16).

The initial length of the logwood bundles was 260 cm. On the 8.8.2008 2 pieces of firewood and discs of wood for moisture samples were cut off from the bundles. Following these actions, the remaining bundle length was approx. 196 cm for the remainder of the drying period. Monitoring required that one of each treated logwood bundle types were cut to facilitate further examination of moisture dispersion inside the bundles. Figure 14 shows a diagram of the location of the bundles in the pile and Figure 15 shows the cross-cutting and sampling points.

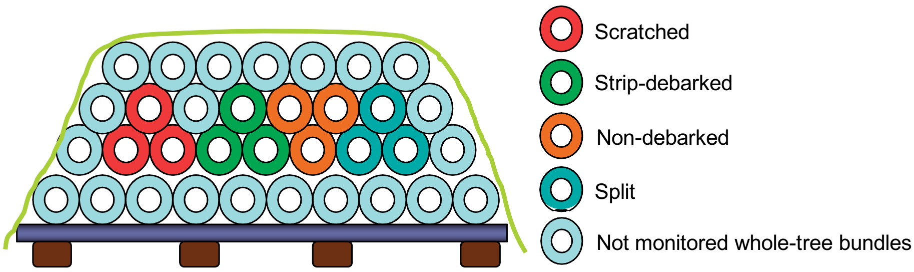

Figure 14. Arrangement of birch logwood bundles in Rautalampi.

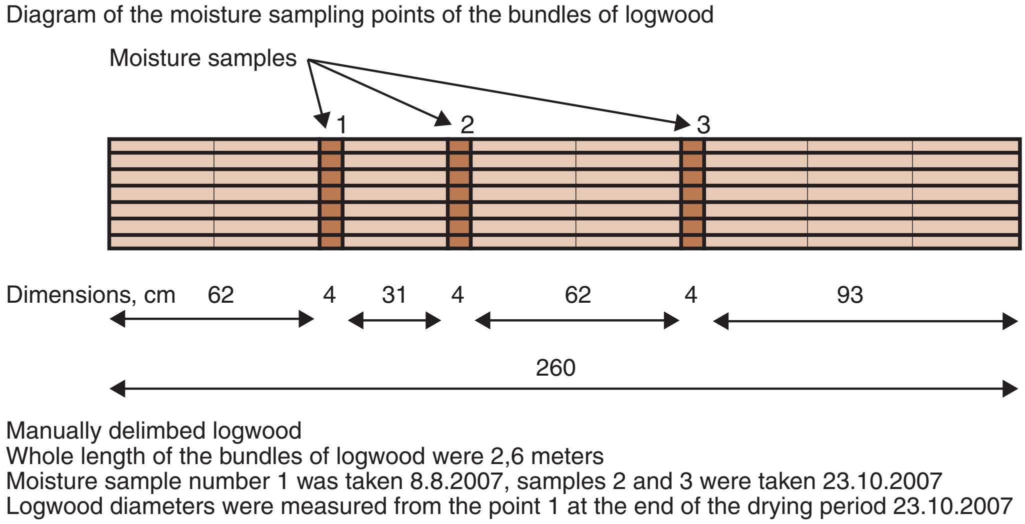

Figure 15. Diagram of cross-cutting of the bundles of logwood at the moisture sampling points and of the point where the logwood diameter was measured.

Figure 16. Pile of bundles in Rautalampi included in the seasoning trial. Monitoring bundles in the middle part of the pile. © Ari Erkkilä.

3.2.2 Seasoning of bundles

The drying of bundles of logwood is shown in Figure 17. The bundles of split logwood reached the target moisture level of 20% after a seasoning period of 5.5 months in September, at which time the measured moisture level of the bundles was 19.6%. Thereafter the bundles began to collect more moisture. The mean moisture level of bundles of strip-debarked logwood was 22.2% at its lowest and that of bundles of scratched logwood was 22.7%. The initial moisture level of bundles of split logwood was lower than that of the others. The moisture level of untreated control bundles was 35.0% at its lowest. Table 8 shows properties and moisture levels of the logwood bundles.

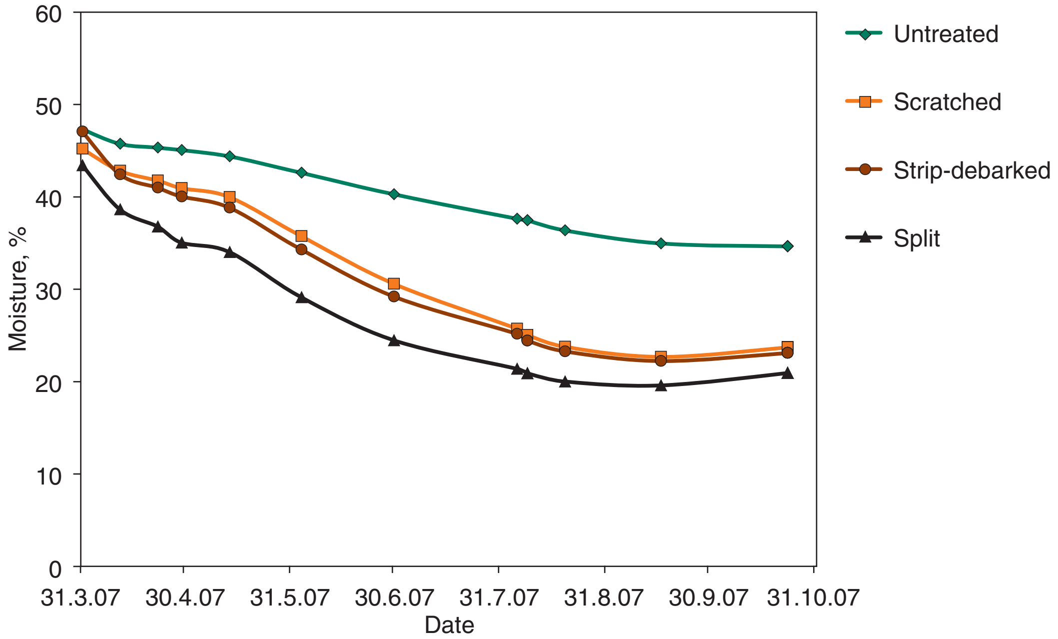

Figure 17. Seasoning of birch logwood bundles in Rautalampi.

Table 8. Means of logwood bundles properties and of the recorded initial, minimum, and final moistures levels.

	Mean diameter of longwood pieces	Share of removed or broken-up bark	Initial bundle mass	Initial, minimum and final moisture level
Bundles of birch logwood, untreated	9.6 cm	0 %	470 kg	47.3 % 34.6 % 34.6 %
Bundles of birch logwood, scratched	10.5 cm	5 %	408 kg	45.2 % 22.7 % 23.7 %
Bundles of birch logwood, strip-debarked	10.5 cm	26 %	463 kg	47.1 % 22.2 % 23.1 %
Bundles of birch logwood, split	9.4 cm	44 %	440 kg	43.9 % 19.6 % 20.9 %

The drying conditions in Rautalampi during the summer of 2007 are shown in Figure 18 and in Table 9.

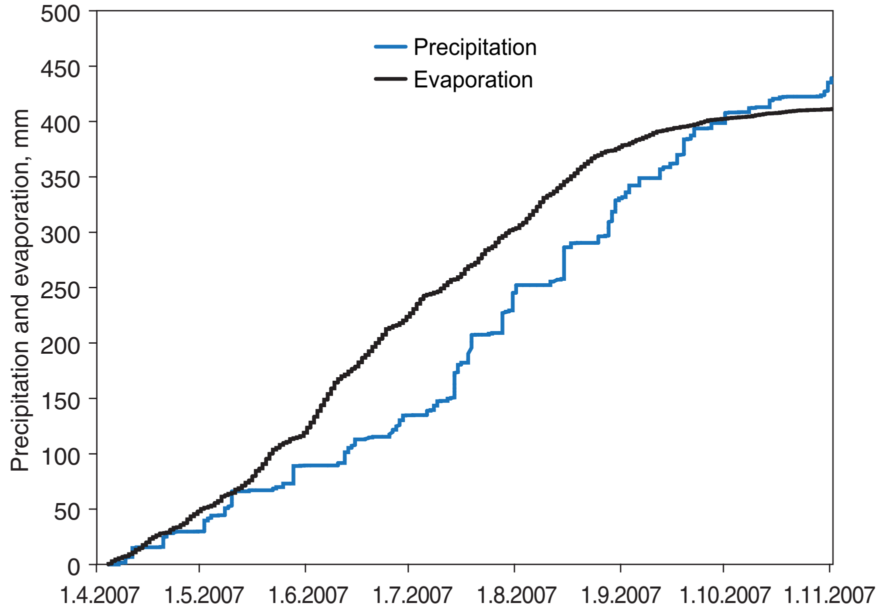

Figure 18. Conditions during the monitoring of drying (precipitation and evaporation) in Rautalampi.

Table 9. Measured precipitation and evaporation sums during the period 4.4–23.10.2007 in Rautalampi and long-term means of evaporation.

Place and date	Evaporation, mm	Precipitation, mm
Rautalampi, 4.4–23.10.2007	410	423
Means of periods 1.4–30.9. during years 1990–97		
Jokioinen	604	
Tikkakoski	428	
Sodankylä	550	

3.2.3 Quality of bundles and logwood

During the monitoring the bundles were weighed 12 times and so each bundle was lifted more than 20 times. The load straps held well and the bundles stayed in the pile formation even though the straps slackened a little. The biggest risk was for the loading strap to break when the loader grapple gripped the bundle. On the basis of random observations, the circumference of the bundles was reduced by about 8 cm as a result of the pieces of logwood being relocated in the bundles and shrinking.

The treated pieces of logwood retained their good quality in the bundles (Figure 19). Some fungal and mould growth formed on the ends of the untreated pieces of logwood (Figure 20). The quality of the pieces of firewood cut off the logwood bundles was extremely good. The cut surfaces were light in color and there was no surface discoloration.

Figure 19. Split pieces of logwood and logwood with the bark broken up by strip-debarking or scratching kept well without significant discolouration. © Ari Erkkilä.

Figure 20. Fungal and mould growth formed on the ends of untreated pieces of logwood. © Ari Erkkilä.

Moisture sample discs were selected from two cross sections of each bundle from different logwood pieces of about the same diameter. The distance between the cutting points was about 65 cm. There was no moisture difference between the cutting points. The thickness of the piece of logwood has a greater effect on the moisture level of the individual piece of logwood than its location in the bundle cross section. The moisture level of the sample discs varied as follows: discs taken from the scratched pieces of logwood varied within the range of 19%–22% (mean 20.5%), those from the strip-debarked pieces of logwood 21%–25% (mean 22.9%), and those form the split pieces of logwood 18%–25% (mean 21.3%).

3.3 Conclusions drawn regarding the seasoning of logwood and logwood bundles

The test results show that the seasoning of birch logwood can be accelerated with relatively minor removal of the bark as long as the bark is broken up in several places on the perimeter of the piece of wood. When 5%–10% of the area of the bark sheath of birch logwood was removed evenly around the perimeter, the seasoning process was significantly accelerated. When the breaking-up of the bark was done evenly along a piece of logwood about 8 cm in diameter at eight points along the perimeter of the piece of wood by scratching, the seasoning time of wood split using a band saw was reached for the target moisture level of 20%. About the same rate of seasoning was achieved by strip-debarking the pieces of logwood on four sides by removing strips 2 cm in width. When bark is scratched, considerably less bark is removed when compared to strip-debarking, which results in approx. 30% of the bark being removed. A good result was achieved also with mere slashing of birch bark, the seasoning time being about 20% longer when compared to wood split using a band saw. The doubling of the diameter of birch wood increased the seasoning time of split wood 2.5–fold. It was possible to almost halve the seasoning time of split wood by executing one scratch, slash or narrow strip-debarking in the remaining bark. A groove 1 cm in depth caused more effective evaporation of water than strip-debarking of the same width.

When seasoning pine wood, minor removal or breaking up of the bark at several points did not produce as good a seasoning results as was achieved with birch. The seasoning of pine wood accelerated only after more than 30% of the bark had been removed. This involved strip-debarking consisting of four strips, each 2 cm in width. Resin was extruded where the bark had been broken up, and therefore minor breaking up or removal of bark was not enough to accelerate the seasoning of the wood. The results obtained with pine wood are based on a single test. However, this result is in agreement with earlier observations and experiences.

The results obtained in the field seasoning trial with logwood bundles support the seasoning results obtained for individual pieces of logwood in the laboratory. Breaking-up of the bark evenly around the piece of logwood accelerated seasoning as much as strip-debarking did. Indeed, the logwood dried well even in bundles when considering the conditions of the summer. Only split logwood dried to a moisture level below 20%. Considering the differences in initial moisture levels, logwood treated with strip-debarking, scratching, and splitting dried equally well in bundles. Covering the pile immediately at the initial stage of seasoning did not appear to hinder the seasoning of the bundles, but it did prevent them from getting wet and becoming discoloured when it rained. Visible fungal and mould growth formed only on the ends of untreated pieces of logwood.

The obtained seasoning results can be made use of in the processing of firewood and also when producing raw material for chipping. This presupposes the inclusion of new properties in firewood processing machines. For example, it is possible to embody mechanical improvements in the felling head of a harvester or in feed component of a whole-tree baler, and when aiming to dry wood these can then be used to break up the bark of the wood more than is done in normal processing. The results obtained show that there is hardly any need to remove the bark of birch wood in order to accelerate seasoning as breaking it up is enough. This means that the dry matter loss can be minimised. The traditional strip-debarking treatment can be swapped for the scratching treatment or the slashing treatment or the shallow groove treatment depending on the most useful technical solution available. Scratching the bark of split wood as a means of accelerating the seasoning process could also be applied in the making of short-cut split pieces of firewood. The evaporation occurring via the ends of pieces of firewood is of great significance. The situation was different in this study which dealt with the seasoning of logwood. However, it would also be worthwhile to develop a technical solution whereby braking up of the bark could be executed in the firewood processor in addition to the splitting action. This could be used to accelerate the seasoning of short-cut split pieces of firewood as well and to get the moisture distribution inside the pieces of firewood more even.

It is useful to note when applying the results that the effect of the treatments was compared to seasoning of wood split using a band saw. One test result was that birch wood split with an axe dried about 25% faster than wood split by sawing. In practice, splitting as executed when using firewood processors corresponds to axe splitting.

4 Firewood production from partially debarked logwood

4.1 Alternative ways of intensifying the production of firewood

The method most commonly used in the production of short-cut split firewood is the one where the trees are felled as logwood motor-manually or using a single-grip harvester, hauled to the roadside, and from there while still green to the "chopping" site to be cross-cut and split for seasoning to begin, and then to be sold. Firewood processors process one stem at a time. The firewood seasoning takes place as short-cut split pieces in various handling units or as bulk wood either resorting to natural seasoning or by using various dryer solutions. The disadvantages of the method are its handling needs, ineffectiveness of harvesting of logwood, and ineffective cross-cutting and splitting of the small-diameter raw material. Indeed, pulpwood is being used as the raw material of firewood by professional firewood producers as a means of improving the productivity of short-cut split firewood. The seasoning of short-cut split firewood in bulk requires care to ensure the good quality of firewood offered for sale. The foremost quality properties influenced by seasoning include low moisture level and elimination of microbial growth and discolouration.

There are several methods for intensifying the production of short-cut split firewood. One possibility is to prepare the short-cut split firewood already in conjunction with timber harvesting using a harvester. Then the remaining work stages are forest haulage and long-distance transportation, the seasoning of the firewood, and selling of the seasoned firewood. Solutions have been presented for this kind of "on-the-stump" production of short-cut split firewood (Voutilainen 2007a). When considering the test arrangements for seasoning trials with logwood bundles, the applicability of this kind of a solution to the splitting of logwood was tried. The experiment was conducted using former machine contractor Martti Kauppinen's so-called *klapimoto* (firewood processor), which, in addition to delimbing and cross-cutting logwood into firewood length, also executes the splitting stage using a blade attached to the felling head (Keto 51). The splitting and cross-cutting to provide short-cut split firewood went well using the machine, but the splitting of longer birch logwood in a controlled manner (Figure 21 and 22). Nokka-Kone Oy has also demonstrated a firewood harvester based on a stroke harvester which fells, delimits and splits the logwood and cross-cuts the firewood material directly into a seasoning container (Voutilainen 2007b).

Figure 21. Successful splitting of logwood. © Ari Erkkilä.

Figure 22. Splintered wood produced in mechanised splitting. © Ari Erkkilä.

A means of improving effectiveness is to process the wood raw material in the production chain as far as possible in the form of logwood. In fact, a mode of production has been developed in Finland whereby the delimbed stems are debarked at the landing using a debarking machine, which results in about half of the bark being removed. PR-Halot Oy's operations model is such that partially debarked stems are seasoned as such sheltered from rain (Erkkilä et al. 2006). Cross-cutting into shorter lengths and splitting take place before delivery to the customer. The quality of the firewood has been good when applying this procedure.

The efficiency of the handling of the raw material for firewood in logwood form may be further improved by multiple processing and bundling. The purpose in bundling logwood is to improve efficiency in loading and transportation, to improve the efficiency of the treatments related to seasoning, and to improve the efficiency cross-cutting and splitting. In addition to felling and delimbing of logwood, strip-debarking and splitting can be carried out in conjunction with harvesting.

One alternative is to construct splitting or strip-debarking and bundling devices for mounting on forest haulage machinery. The same procedure can be carried out also at the landing or cross-cutting and splitting site. However, this means losing the advantage to be had from improved efficiency when compared to bundling in conjunction with harvesting, but the higher efficiency resulting from multi-tree processing can be utilized in seasoning and transportation. It depends on the desired product form whether the seasoned wood is delivered as logwood bundles or as short-and split firewood.

Tools for bundling up and seasoning of 1-metre-long split firewood have been developed in Central Europe. In Central Finland, too, there is a splitting-and-binding device for 1-metre-long split firewood; the device is designed and constructed by a local entrepreneur (Veli Savolainen, local district of Sumiainen). The bundles of firewood are seasoned and then delivered to the customer's site and then cross-cut into shorter lengths using a chainsaw with a long chain bar (Erkkilä et al. 2006).

The following deals with the work stages involved in partial debarking and forming of logwood bundles with the aim of promoting seasoning and improving productivity. The assessment is partly based on the tests conducted in this study and partly on the related literature.

4.2 Braking-up of the bark

Breaking-up the bark promotes the seasoning of wood. The breaking-up of bark should be implemented in conjunction with the harvest of the wood without extra work stages being necessary. Tests were conducted in February 2007 with partial debarking of stemwood using various blade constructions embodied in the harvester head. Mainly making of short-and-split firewood was thought of as the application for logwood, which is why the aim was to achieve a tidy debarking outcome. The alternatives for breaking up the bark were treatments of varying degrees. Mere slashes do not really remove any bark at all. The next least-bark-removing treatment is scratching whereby bark is broken-up down to woody tissue, but bark is not actually removed. The actual removal of the bark can then be done as strips of varying width.

Various knife blades for slashing, a blade for scratching, a gouge-like blade, and a plough-like blade were tried out as tools for implementing the above modes of breaking up the bark. The tests were conducted using the loader of a Terri mini-forwarder onto which a Naarva stroke harvester had been mounted. Each blade model was mounted in turn onto the harvester head's delimbing blade. The delimbing blades of the stroke harvester did not follow the contours of the surface of the piece being processed; instead, the blades sometimes bit into the wood and at other times they were off the surface of the wood. The test blades did not produce the desired processing outcome along the full length of the piece of wood. The tests revealed, however, the type of blades suitable for the purpose. The tests were conducted with pieces of birch, but the scratching blade was also tried on pine. The blades used in the tests were made from structural steel and the purpose was merely to examine blade models, not their wear-resistance. Concurrently with the debarking tests, we conducted seasoning tests, and the results obtained indicated that bark should be broken up at several points on the perimeter of the piece of logwood.

The knife blades installed behind the delimbing blades, whose blade angle with respect to the wood surface was about 45°, slashed the birch bark well. Fixed in position, without tilting of the blade, the installed double knife did not follow the contours of the piece of wood well enough and part of the time it made a single slash. The double-blade assembly was tested using two distances between the knife blades, 30 mm and 50 mm. Scraping blades were tested together with the knife blades, the purpose being for the scraping blades to remove the bark from between the slashes. The scraping blade tended to easily take too thick a shaving of the wood when the delimbing blades were too close to the actual wood. The knife blades in contact with the wood over a considerable length loosened shavings of wood as the piece of wood made sideways motions within the harvester head.

The scratching blade consisted of the hard-metal spike of an asphalt cutter fastened behind the delimbing blade so that the point of the spike extended 1–2 cm inside the delimbing blade. The spike was inserted at an angle of about 90° with respect to the wood and the point of the spike was conical. The spike made a 2–4 mm wide scratch bearing the wood surface and loosening small amounts of wood and bark.

Debarking also was done using an open gouge-like knife blade. The purpose was to implement a debarking mark resembles the mark of a gouge. The debarking itself was successful, but the width of the gouged mark was dependend on the distance between the delimbing blades and the surface of the stem.

The plough blade had a plough-like blade mounted at an angle of about 90°. The blade was sharpened to an angle of about 45°. The blade tended to very easily bite deep into the wood and it has a great sideways force if only half of the blade struck the wood. Indeed, the part holding the blade bent during the test because of the sideways force.

The results of the tests showed that the slashing knife blades and the scratching blade operate well. The gouge blade also worked. The parts holding the blades must be flexible or the blades need to be made to follow the contours of the wood better. It is not sensible to design the blade to remove the bark in wide strips, at least not when dealing with birch logwood, because the benefit to be gained from accelerated drying can also be achieved by implementing several narrow debarking marks around the piece of logwood.

When applying blade models in practice and fastened to the harvester head, the blades need to attached so that they can follow the contours of the pieces of wood. These solutions can be machine-specific. In order that the same harvester head can be used for felling and onward processing of the stems for both pulp and energy use, it must be possible to steer the bark-breaking blade assemblies by means of electrical or hydraulic actuators.

4.3 Bundling of logwood

4.3.1 Bundling of freshly-felled logwood

The bundling of logwood before drying can be done at the stump in conjunction with felling, in conjunction with forest haulage, at the intermediate storage point, or at the terminal.

Bundling in conjunction with felling

Biotukki Oy has developed the Fixteri whole-tree-baling unit involving bundling on the logging strip when practicing combined harvesting of industrial wood and energy wood (Figure 23). The pieces of wood tend to lose some of their bark in the baling stage and also the rollers of the in-feeding device break up the bark. However, the drying could be further improved by further breaking up the bark of stems to be harvested for fuel. When producing chips, there would be no need to delimb the raw material if the bark of the pieces of logwood could be broken up, using the baler's feeding device.

In regards the production of raw material for the short-cut split firewood chain, the device should be equipped with delimbing and strip-debarking devices and possibly with a splitting device so that the pieces of logwood could be brought as ready as possible to the converting site. For example, delimbing and strip-debarking could take place using a grapple and alternatively splitting in conjunction with feeding into the baling device by means of appropriate in-feed table arrangements. Baling would be done in the way it is done at the present. The largest stems could be hauled directly to the terminal in the traditional way to be cut short and split, if the capacity of the splitting device is not adequate. The bundles of logwood could be left on the strip to dry or they could be hauled on a forwarder to the storage site to dry.

Previously, balers have been developed for baling logging residues, e.g. John Deere's Fiberpack baler, Komatsu's Valmet WoodPac baler, and Pinox Oy's Pinox baler. Woodpac and Pinox balers are used in a combination machine. The baler can be detached from the prime mover enabling the same machine to be used as a forwarder.

Fixteri whole-tree baler binds the bundles by turning the bundle inside the machine and thus causing the baling cord or baling net to wrap itself around the bundle. John Deere and Pinox Oy have solved this stage by having the binding device wrap the cord around the bale.

Figure 23. Fixteri whole-tree baler for harvesting pulpwood and energy wood. © Ari Erkkilä.

Bundling in conjunction with forest haulage

In another supply chain, the harvester is used to fell the trees and then delimb, strip-debark and cross-cut them, e.g. to 3 metre-long logwood, and then deposits them in piles to be picked up and hauled to the roadside by a forwarder. The forwarder could be equipped with splitting-and-bundling equipment enabling bundles of logwood to be produced ready for taking to a roadside storage point or a terminal to dry. Once dry, the bundles of logwood would be either sold as bundles or the logwood would be cross-cut as bundles to produce short-and-split firewood.

Both of the above treatment chains include drying in bundles. The piles of bundles are dried under cover to prevent rain water from causing harmful discolouration.

4.3.2 Bundling of dry logwood

Logwood partly debarked or split in conjunction with harvesting can also be dried loose, either on the strip or at the landing. The pieces of logwood and split logs that have been allowed to dry loose are either bundled using the forwarder-mounted bundling device or they are hauled loose to the terminal to be bundled there if this is necessary, e.g. to enable their long-distance transportation. Cross-cutting to produce short-cut and split firewood would take place as bunch-cross-cutting using purpose-built cross-cutting equipment. Bundle cross-cutting is dealt with later on.

4.4 Binding of logwood bundles

Bundle binding using a whole-tree-baler was described above. Logwood bundles can also be prepared using simpler tools, although then the efficiency of bundling is correspondingly lower. Using the automatic and manually operated strapping machines used in the packaging industry could be one solution when binding of logwood bundles. These machines are designed indoors use where rubbish, snow and low temperatures are eliminated.

Manually operated strapping machines are available running on battery and mains power, as well as pneumatic and mechanically operated models. The straps used are either plastic or metal. The plastic straps can be tied end-to-end using purpose-made buckles. These kinds of straps cannot be made very taut. Mechanical linking of plastic straps involves using heat-, friction- or lock-based joints. Various kinds of strap locks or non-lock methods are used in joining the ends of metal straps.

The following is a presentation of devices suitable for binding logwood bundles. The information presented has been collected from the various manufacturers' and retailers' Internet websites, and the contact information is available at http://www.suomenpakkausmateriaalit.fi/indexFIN.html.

4.4.1 Manual binding and auxiliary equipment

Manually binding is a feasible option when collecting the logwood from the harvesting strip is done using the forest owner's own resources. The method involves collecting the freshly-felled or dried logwood from the strip into the forestry trailer of a tractor or using a skidding grapple, that could be used to carry out the binding (Figure 24). Bundling in conjunction with tractor-based forest haulage could be arranged with a binding device attached to the trailer or at the point in time when the pieces of logwood are gripped in the loader grapple. A bunch of logwood held in the grapple is also ready for binding.

Figure 24. A skidding grapple, which can be used in forming bundles and as an auxiliary tool for bundling of split firewood. © Ari Erkkilä and http://www.posch.com

The binding of bundles by tying knots is possible when cords are used as the binding material. Piippo Oy is a manufacturer of baling cords used in mechanical baling. Metal wire can also be used in manual binding. Both of these binding materials are available on reels and automation or some other means of facilitating the binding can be arranged. The weather conditions are no obstacle to binding.

When bundles of logwood are bundled manually using fibre or plastic straps, metal or plastic buckles are needed. The buckles do not need any auxiliary fastening tools, but hand-operated strap tensioning tools are commonly available (Figure 25). Plastic strapping material for both manual and mechanised methods are available. Strapping material with tensile strength varying from 220 kg to 1050 kg is available with the width and thickness of the material varying accordingly.

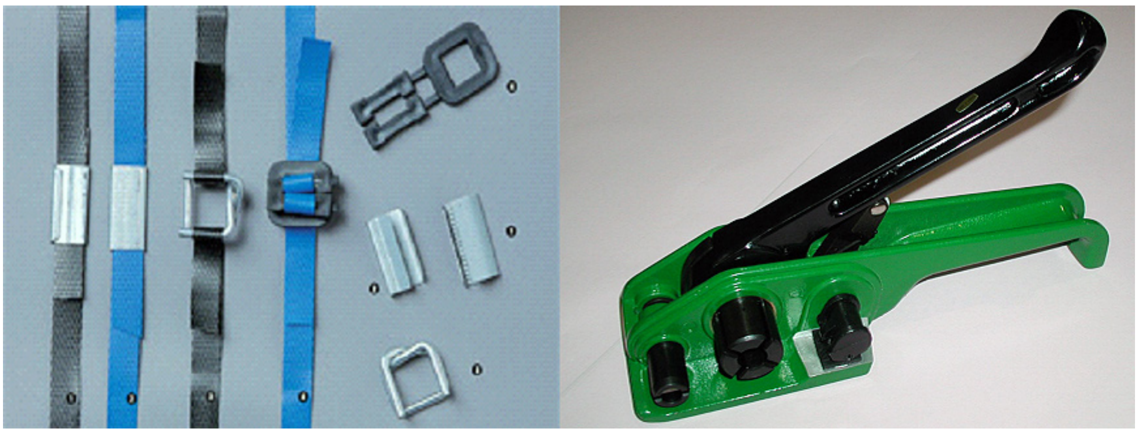

Figure 25. Strap buckles for plastic straps and a tensioning tools for metal buckles. Photos: http://www.suomenpakkausmateriaalit.fi/.

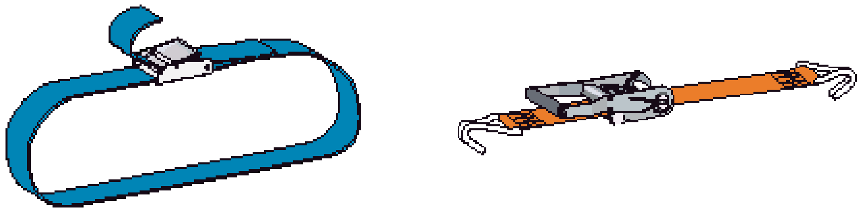

Figure 26. Top left, mini-binding belt and on the right a ratchet-lock belt. Photos: http://certex-fi.wd6.se/UserFiles/FI/4%20Kuormansidontavälineet.pdf

Load-binding straps equipped with locking devices are well suited for binding logwood bundles in small-scale production (Figure 26). Suitable binding belts include ratchet-lock and mini-binding belts, which are both 100% polypropylene. Ratchet-lock belts are available for quite heavy-duty use and they can be used to tighten a logwood bundle into a more compact form. Ratchet-lock belts come in several widths (25 mm–100 mm) and with varying strengths from 400 kg to 9000 kg. The belts have a binding strength of 800 kg–18000 kg.

Another option is to use mini-binding belts, although these cannot be used to tighten the bundle itself; then one must tighten the bundle using some form of other external force (ratchet-lock belt, hydraulics). There are mini-binding belts of at least two widths, 25 mm and 35 mm, provided with locking devices. Their nominal strengths are 250 kg and 1100 kg, and they come in lengths up to 5 metres.

These belts tie up capital because three per bundle are needed to ensure that the bundles do not break up. With careful bundle handling, the belts can be used several times, and this, of course, will reduce the costs.

4.4.2 Manually-operated strapping machines

Strapping using plastic and steel straps is possible using a variety of manually-operated tightening and joining devices. The devices are intended mainly for strapping objects regular in shape (e.g. pallets, bales, wood-processing industry products). Especially for objects, which are round and with irregular surfaces, there is a purpose-designed strapping machine, which uses a metal lock as an aid.

Metal locks, manually placed or applied by a purpose-made device and then pressed around the plastic straps by the device, are used in joining the ends of plastic straps. The manufacturers warrant the plastic straps retain their tautness despite changes in the form of the packaged product caused by its handling, and the same cannot be said about steel straps. Plastic straps enable reduced tensile strength to be used than is the case with steel straps, and the use of plastic straps includes savings in material costs.

The advantage of using steel straps is that the joints are without locks because the strapping machines execute so-called piercing joints. Depending on strap grade, the strength of the joints is approx. 80% of the tensile strength of the strap and the manufacturers warrant that the joint reduces the total costs of strapping by approx. 10%.

No information is available on the applicability and functioning of strapping machines in winter and forest conditions. According to manufacturers, pneumatic tools can be used at temperatures lower than those suitable for such battery-powered tools whose batteries begin to discharge at temperatures below zero. Battery-powered tools can be used briefly even in very cold weather if they are kept in a warm facility between uses. Batteries must not be kept at temperatures below -10ºC for lengthy periods of time and keeping them in the rain is altogether forbidden.

Pneumatic tools as such are not sensitive to becoming wet, but the strap joint may not be so good, e.g. because of snow, slush or dirt. The strength of the joint can be influenced by adjusting the welding time. In general, it can be said that using welding strapping tools outdoors may have its problems because of different weather conditions. There are many models of steel strapping tools, which can be readily used the year round outdoors, but then the tightening and locking are done manually.

Battery-operated (rechargeable) machines are independent of the location of the power source. These machines are light and can be operated with one hand. They are intended for plastic strapping solutions. The ends of the strap are placed one on top of the other and then the machine makes the strap tight and applies friction welding to fuse the ends. Depending on the strap grade, the strength warranted for the joint is about 75% of the tensile strength of the strap. Although it is possible to use such a machine in all the branches of industry, using it in cold weather can become problematic. The charging current could be supplied from a tractor or from a stand-alone generator, but still a cold strap may weld poorly. Tensioning force up to 3000 N.

Plastic straps can be fused using mains-current-operated welding plastic strapping machines running at 220 volt (50 HZ, 1-phase) lighting supply power. The device can be used to join straps 8–9 mm in width.

Pneumatically-operated machines are available for both plastic straps and steel straps. These machines can use relatively thick plastic strap, which is then welded applying friction welding. The tensioning force is close to 4000 N. The operating pressure is 4–6.3 bar.

Pneumatically-operated steel-strapping machines can achieve similar joint properties to those of piercing joints as can be achieved using hand-operated machines, the advantages being higher capacity and even tensioning force. Pneumatic machines are available as piercing-joint and lock-joint models. The required operating pressures and consumption are similar to those of the former.

Strapping automats are used for purposes such as packaging of sawn timber. Similar devices could be used at terminals for bundling logwood. Such a strapping machine has a conveyor which takes the bundles into the bundling framework. The binding can be made using plastic straps, in which case the straps are welded using the heat welding method, which guarantees a durable joint also in variable and dirty operating conditions.

The end of the steel straps are connected to each other by means of a piercing joint, which is better compared to using separate locks. The use of piercing machines can significantly reduce the total costs of strapping.

If necessary, a strapping line can be equipped with a material compactor, which in the case of logwood pieces could be clam-like to produce round bundles.

4.5 Cross-cutting of logwood bundles

The current production chain with short-cut and split firewood is that the pieces of wood a cross-cut singly. The productivity of this can be improved by cross-cutting multiple pieces at the same time. In order to determine the final moisture level of the dried logwood bundles, the bundles under drying monitoring were cross-cut for the purpose of taking moisture samples. The success of cross-cutting was determined at the same time. The cross-cutting was done using a chainsaw and using a sawing device made for cross-cutting bundles of boards.

There are commercial solutions available for 1-metre-long logs and bundles of sawngoods (Figure 27).

Figure 27. Device for cross-cutting bundles. © Ismo Tiihonen.

4.5.1 Cross-cutting using a chainsaw

The study included conducting a practical experiment in cross-cutting bundles with a chainsaw. A chainsaw (Stihl 240) was equipped with a chain bar 90 cm in length. (Figure 28). A logwood bundle was lifted into the rack, which had also been used as an aid in binding the logwood pieces (Figure 29). Cross-cutting the bundles using the chainsaw went well. The bundles stayed in place well within the sawing frame despite the looseness of the binding straps. The binding straps were loose partly due to the many bundle treatments and partly due to reduction in the size of the logwood as they dried. It was possible to tighten the binding straps about 8 cm, i.e. the diameters of the bundles had diminished by an average of approx. 3 cm. A tightly-bound bundle was more difficult to saw with the chainsaw than a bundle which had become slack. It was easier to saw logwood in round form than logwood, which had been split. Split logwood was more likely to begin to vibrate and jam the chain.

The sawdust and other rubbish stays among the firewood, and it needs to be removed by means of screening or in some other way. Screening was tried out simply with screening plates (Figure 30), which have the effect of ridding the pieces of firewood of sawdust and other rubbish as they roll over the screens. The angle of inclination of the screens was 32° and the screen hole size was 50 mm. The dryness of the logwood and sawdust promoted the removal of the sawdust and other rubbish. When dealing with freshly-felled wood and damp conditions, sawdust is probably the most difficult to get rid of.

Figure 28. The chainsaw used in cross-cutting. © Ari Erkkilä.

Figure 29. The rack used in binding and cross-cutting the bundles. © Ari Erkkilä.

Figure 30. Dry sawdust was readily separated in screening. © Ari Erkkilä.

The productivity of cross-cutting logwood bundles using a chainsaw can be estimated as follows; For example: with the diameter of the logwood bundle being 70 cm and its length being 260 cm, the amount of wood in the bundle will be approx. 0.5 solid cubic metres. When a bundle is cross-cut to firewood length of 32 cm, each bundle is lifted once, there are 7 sawing operations, and there are 6 transfers for each bundle. In trial cross-cutting, the time consumed for one sawing operation varied between 20 and 30 seconds, and averaged 25 seconds. When the transfer of the bundle to the sawing frame is estimated to take 7 seconds, and lifting the bundle into the sawing frame to take 10 seconds, a productivity of 8 solid cubic metres per hour is calculated, which corresponds to about 20 loose cubic metres of short-cut and split firewood. If the bundle does not need to be moved between the sawing operations, but the saw operators instead moves, using 3–4 seconds in doing so, the productivity will be 8.5–9 solid cubic metres per hour. In practice, productivity of cross-cutting bundles depends a lot on the way the work is organised and possible disruptions. The productivity given above is only a rough value. It should also be taken into consideration that any round pieces of firewood need to be split as well.

4.5.2 Cross-cutting of logwood bundles at a sawmill

Siparila Oy upgrades sawngoods for interior and exterior building purposes and to be used in interior decoration. The company uses a Holtec chainsaw for cross-cutting bundles of sawngoods (Figure 31). The equipment consists of in-feed rollers and the chainsaw unit plus a discharge conveyor. The saw's cross-cutting bar is manually controlled. The saw bar was forced against the bundles steadily in the trials because the logwood pieces in the bundle had room to move and tended to readily cause the chain to jam. When a strap was used to bind the bundle to form a tight package at the cross-cutting point (Figure 32), the chain no longer jammed. One means of eliminating this phenomenon technically is to use a compaction tool supporting the bundle. Maximum short-cut and splitting capacity was not tested. The end of the logwood bundle being cross-cut must be unobstructed as otherwise the lowermost pieces of wood are forced against the bar and this causes the chain to jam. Moreover, the short-cut pieces of firewood must be free to fall immediately after being cut so that they do not block the saw bar when it is raised back to its "home position". Sawdust remained among the prepared firewood despite a sawdust vacuum being used. The gap produced by the saw was about 10 mm wide. A narrower chain would be better for cross-cutting logwood. The logwood pieces and sawdust were dry, and consequently it would have been possible easily to screen off the sawdust.

Figure 31. Cross-cutting device for board bundles. Manufacturer: Holtec. © Ari Erkkilä.

Figure 32. A tight strap prevented the sideways movement of the pieces of logwood, and this made the job of cross-cutting easier. © Ari Erkkilä.

4.6 Conclusions regarding the production chain

The scope of the planned firewood production and resulting investments, affect the design of the production chain for the use of partly debarked logwood as a material for short-cut and split firewood. The drying tests demonstrated that the drying of firewood can be done in logwood bundles and that sufficient drying can be achieved over one summer in good weather conditions. The assisted (artificial) drying of logwood bundles was not studied, but it is quite likely that this could, for example, be done in a kiln as used with sawn goods. Bundles formed manually using load-binding straps withstood the treatment quite well. In regards to mechanised baling of logwood, there are only prototypes under development at the moment.

A matter of importance from the point of view of production efficiency would be to achieve suitable breaking up of the bark of logwood pieces already in conjunction with harvester-based wood harvesting or at the point where the logwood material is fed into the baling unit. This would enable extra treatment rounds to be avoided. When harvesting wood motor-manually, there is a need for a separate work stage for partial debarking and for forming of bundles.

The cross-cutting of logwood bundles into short-cut and split firewood succeeded with good efficiency also when using a conventional chainsaw. The tested device for sawing of board bundles was excessively heavy-duty. It would be relatively easy to develop a sawing device suitable for professional firewood production and more efficient than a chainsaw. The sawing device could, for example, be based on a chainsaw mounted on the felling head of the harvester.

From the point of view of the usability of the short-cut and split firewood, the issue at stake is the need for splitting. The splitting of crooked logwood is difficult. Some of the alternatives to be tried out could include a solution based on the joint operation of circular saw blades and a splitting knife and the use of splitting discs. One-metre-long and even longer split firewood logs have been produced using a splitting-disc solution (Ryynänen 1981). The customers' user habits and wishes have an effect on what the dimensions of a piece of finished firewood can be.

The easiest option from the viewpoint of the firewood supplier is to leave the splitting to the customer. However, it is certainly possible with present-day firewood processors to produce short-cut firewood from one piece of logwood at a time.

The costs of the short-cut and split firewood production based on either partially debarked or split logwood, either as bundles or as loose pieces of logwood, are difficult to calculate at present as there are no practical solutions available. Mechanical wood harvesting and multiple-processing are possibilities whereby small-diameter wood can be converted into firewood with less costs and at the same time achieve the same efficiency in cross-cutting and splitting as when dealing with large-diameter industrial wood nowadays. Drying the wood as logwood is more efficient than drying as finished firewood, and when cut short and split when dry the sawn surfaces are free of discolouration. The results obtained may give hardware developers new ideas and new productive solutions for application in the firewood production chain.

5 Effect of bark on combustion emissions

5.1 Properties of a stemwood and bark from the viewpoint of combustion

The elemental composition of wood is such that it is formed mainly of carbon, hydrogen, and oxygen. Their share of the mass of the dry matter in wood is about 99%. The concentration of nitrogen is usually less than 0.5%. Wood contains less than 0.05% of sulphur. There is little elemental difference between different woods (Moilanen et al. 1996, Laine & Sahrman 1985, Wilén et al. 1996, Nurmi 1993).

Table 10 shows values containing the variation ranges of all common tree species in Finland. Generally speaking, the calorific value of tree bark when compared to that of the stemwood of the same tree species is a little higher, and so are the nitrogen and chlorine concentrations. A higher nitrogen concentration causes more NO_x emissions and an elevated chlorine concentration may promote heart corrosion in power plant boilers. Table 11 shows the ash contents of various tree species and parts of trees.

Table 10. Elemental comparisons of wood and bark (Moilanen et al. 1996).

Element	Wood Weight-% of dry matter	Bark Weight-% of dry matter
Carbon (C)	48–50	51–66
Hydrogen (H)	6–6.	5.–8.
Nitrogen (N)	0.5–2.3	0.3–0.8
Oxygen (O)	38–42	24.3–40.2
Sulphur (S)	0.05	0.05
Chlorine (Cl)	< 0.01	< 0.01–0.03

Table 11. Ash content of wood (Taipale 1996, Wilén et al. 1996, Tahvanainen 1995).

Wood fuel type	Ash content in dry matter, weight-%
Split firewood, short-cut split firewood	0.5 - (1.2)
Whole-tree chips, pine	0.6
Whole-tree chips, mix of tree species	0.5
Birch chips	0.4–0.6
Harvesting residue chips, spruce	2.0–6.0
Stump chips	0.50
Willow chips	1.7
Sawdust, with bark	1.1
Sawdust, pine, without bark	0.08
Wood shavings	0.4
Pine bark	1.7
Spruce bark	2.3–2.8
Birch bark	1.6

When examining the values shown in the above tables, one should bear in mind that the properties of trees which have grown on different sites vary. The substrate does, of course, influence the wood properties.

The carbon and hydrogen concentrations of the bark are usually higher than those of stemwood. Consequently, the calorific value of the bark is higher than that of clean woody material, and this is a positive aspect from the viewpoint of combustion.

However, bark does have many negative properties, which are reflected mainly in the emissions resulting from the burning of bark. The nitrogen concentration in the bark is normally higher than that in stemwood. Almost all of the nitrogen contained in wood is transformed into the nitric oxide emissions of combustion gases. Also the sulphur concentration of bark is usually a little higher than that in stemwood, and therefore its sulphur dioxide emissions are also a little higher. The higher chlorine concentration can cause heat corrosion in power plant boilers.

The ash content of bark is higher than that of stemwood. The higher ash content can cause some problems in the functioning of the grate when burning chips. When using firewood, bark is not a problem except that it means that more ash is being formed.

The amounts of alkali metals and alkali earth metals is higher in bark than in stemwood, and this probably contributes to the increase in the amounts of small particles formed during combustion. According to research findings, small particles contain, for example, a lot of particles originating from vaporised potassium and zinc. Figure 33 shows the composition of bottom ash and fly ash formed when burning birch. On vaporising, potassium forms different compounds which depend mainly on fuel's sulphur and chlorine concentrations. The dominant proportion of potassium in fly ash also becomes evident from Figure 33. By way of a summary regarding the properties of bark and stemwood, it can be stated that bark material has a higher calorific value; this is explained by the higher carbon and hydrogen concentrations. The ash concentration of the bark is higher than that of stemwood. The concentrations of nitrogen, sulphur, chlorine and alkali and alkali earth metals are higher in bark, and they add slightly to the emissions of combustion.

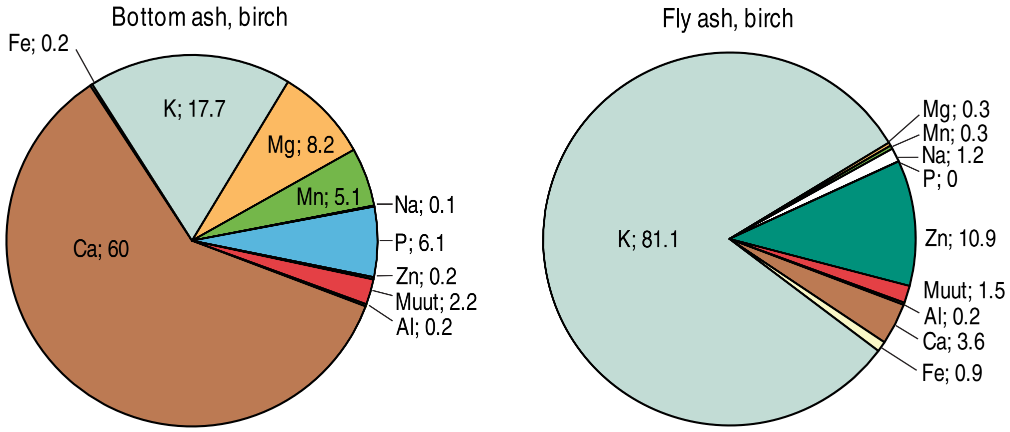

Figure 33. The composition of bottom ash and fly ash formed when burning birch. Source: University of Kuopio, presentation in conjunction with the PIPO Project's seminar in Tampere, 16.11.2005.

5.2 Effects from the viewpoint of combustion in practice

5.2.1 Combustion of chips

When the wood is burnt as chips, the amount of bark does not really have any practical significance as long as the proportion of bark does not become excessive. If the chips are made of non-debarked woods, NO_x, SO_2 and particular emissions may be a little higher.

5.2.2 Combustion of short-cut and split firewood

The effect of the amount of bark when burning short-cut and split firewood is similar to that of burning chips. The amount of small particles originating from mineral matter may be a little higher for non-debarked firewood than for partly debarked firewood. Experience has shown that birch bark produces a lot of black smoke, mainly soot, during the first stage of combustion. Partly debarked firewood may produce less emissions than non-debarked firewood. The majority of small particles in the burning of firewood are formed because of incomplete combustion and they consist of small particles which have condensed from tar-like pyrolysis gases. The amount of bark does not have any effect on them.

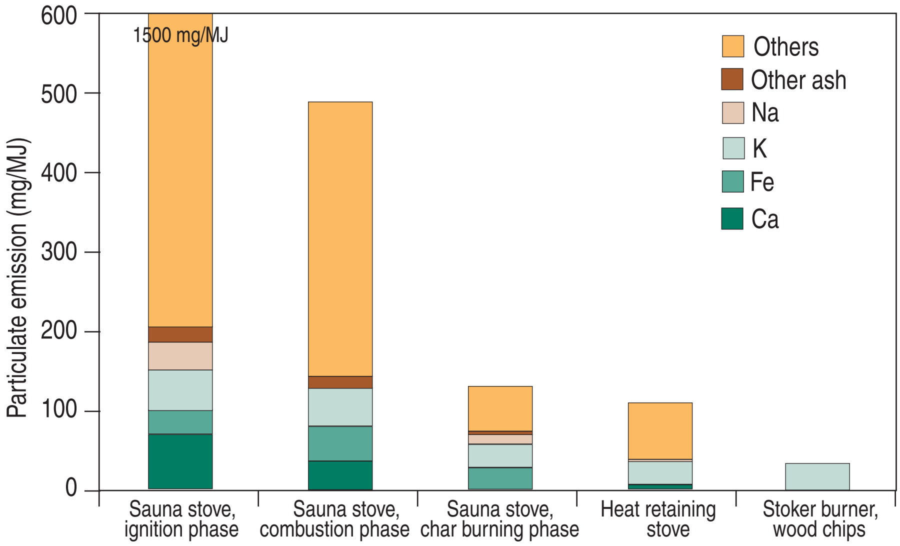

Figure 34. The nominal cation emissions from a sauna stove, a heat-accumulating fireplace, and stoker-based burning of chips. Source: Tissari 2005, p. 98.

Figure 34 shows data on the composition of small particles as measured in the project Puun pienpolton pienhiukkaspäästöt (Small Particular Emissions in Small-Scale Combustion of Wood). According to the results, the amount of particles formed in the combustion of short-cut and split firewood from the mineral matter contained in the fuel is small when compared to the particles formed as a result of incomplete combustion. Particularly at the lighting stage, this is minimal. At the lighting stage, the particular emissions exceed the scale presented in the figure, 1500 mg/MJ, and then the emissions of small particles resulting from incomplete combustion is about 1300 mg/MJ. However, in continuous combustion of wood chips, the particles originate almost entirely from the potassium contained in the fuel.

5.3 Summary of the Effect on Combustion of Reducing the Bark Content

A fuel containing less bark material is slightly better in regards to its combustion properties and it probably causes slightly less emissions than a fuel containing more bark. From the practical viewpoint, this probably has little significance, as long as the proportion of bark remains minor. The partial removal of bark material is of benefit mainly in that it speeds up the drying of the fuel and the fuel becomes more uniform in quality, which is of much greater significance from the viewpoint of combustion.

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Part 2

Partial debarking and covering to promote drying of roundwood for energy in Finland, Scotland and Italy

Dominik Röser, Blas Mola-Yudego, Lauri Sikanen, Robert Prinz, Beatrice Emer and Kari Väätäinen

1 Introduction

At present the use of forest and agricultural biomass for energy is an increasingly important topic, particularly in light of the recent debate on climate change and of employment in rural areas. In order to combat climate change, the EU commission, as well as other countries outside the EU, has set ambitious targets to increase the share of renewable energy sources (Lunnan et al. 2008). In order to meet these objectives, a large share of this increase has to come from forest biomass. In the European context, forest biomass offers the largest and most economic potential as a renewable fuel when managed on a sustainable basis (Röser et al. 2008). However, at the current state of the forest biomass development, the targets set by the EU Commission are a great challenge for the sector. In order to ensure the reliable and sustainable supply of forest fuel new technological solutions to procure and process forest biomass are needed.

One of the biggest challenges to increase the use of forest biomass is the availability and proper use of suitable harvesting technology and methods to meet the growing demand for raw material and at the same time ensure the sustainable use of the forest ecosystems (Röser et al. 2008). Currently, forest biomass technology and supply systems are still under rapid development and in some countries experimental trials have only started recently.

Consequently, methods to produce high quality wood chips for a rapidly growing energy sector are essential for the development of the bioenergy sector, particularly in Central Europe, where a large share of the installed heating capacity is based on small scale heating systems. Small wood chip heating plants, specifically, require wood chips of high quality to ensure unproblematic operation as well as low maintenance cost (Nurmi & Hillebrand 2007).

Due to the climate and rural development policy of the EU demand for wood based fuels, is expected to increase especially in rural areas, which is supporting the establishment of numerous small scale heating plants. However, wood fuel has clear disadvantages when compared to traditional energy sources such as oil or gas, concerning the procurement and handling of the fuel. As a result, the efficiency and economic, as well as environmental sustainability of the entire procurement chain, has to be guaranteed.

There are various factors that are influencing and affecting the quality of wood chips. However, moisture content is considered to be an important quality parameter in dealing with wood based fuels (Pettersson & Nordfjell 2007). Low moisture contents increase the heating value of fuel, improve efficiency of the boiler and reduce transportation costs of wood chips. Therefore, to facilitate the drying process and thereby ensure the availability of high quality fuel in short and long term, supply chains for wood chips should be designed to also account and promote natural drying of timber during the procurement processes.

The bark percentage of the fuel is another important quality factor in the production and combustion of wood chips as well as pellets. The bark's energy density is not as high as that of stem wood and high bark contents also causes high ash contents in the combustion process (Hakkila 1989). This in return will increase maintenance costs of the heating systems and also lower the energy efficiency. As a result, in order to produce high quality pellets or chips the bark should be removed having two positive effects on the fuel. Firstly, the stems to be dried will loose moisture more efficiently when bark is removed and secondly the bark percentage of the end product will be decreased.

In cut-to-length timber harvesting with single grip harvesters, debarking is a well known phenomenon. In Nordic countries, when harvesting timber for pulping or sawmilling, debarking should be minimized in order to get more raw materials delivered to the plant, since the bark is usually burnt in large scale wood boilers. In eucalyptus plantations in South America and Asia, debarking is already fully integrated into existing supply chain. In the production of wood energy partial debarking of stems has been used for decades to promote the drying process. Partial debarking of both boreal broadleaved and coniferous species is known as an effective method to dry timber during storing (Nurmi & Hillebrand 2007). Nonetheless, proper place for storing and suitable weather conditions are important factors that need to be considered.

Nurmi and Hillebrand (2007) noted that the storing of whole trees and stemwood at the roadside landing is likely to lower the moisture content even in Northern climatic conditions. Also Webster (2006) noted that the effective drying of small roundwood stems can be achieved even in Scotland. This trend has also been shown for logging residues and bundles by Pettersson & Nordfjell (2007) in Finland and by Hudson et al. (2003) in Scotland. Studies have also shown that the best drying season is during spring and summer (Nurmi & Hillebrand 2007, Hakkila 1962, Jirjis 1995). The generally positive effect of covering piles to lower the moisture content and maintain the lower moisture content over the winter month was also already noted in several earlier studies (Pettersson & Nordfjell 2007, Nurmi & Hillebrand 2007, Jirjis 1995, Uusvaara, 1984, Lehtikangas & Jirjis 1993, 1995, Heiskanen 1961).

2 Objectives

The objective of the DryMe project was to investigate natural drying of small diameter trees. Furthermore, the effects on the drying process of covering the piles, partial debarking of stems and different locations were tested in order to find new methods to stabilize the moisture content of the woody material in the storage. Drying trials were set up in Finland, Italy and Scotland, utilizing tree species typically used in the area.

The aim of the project was to clarify the following questions:

1. How much can the moisture content of woodfuel in storage be lowered?
2. Can this reduction be maintained during the winter?
3. What are the effects of storage time in the reduction of moisture content?
4. What are the effects of covering on the reduction of moisture content?
5. Are geographical differences in this reduction?
6. Does partial debarking of the stems during harvesting affect the drying process?

The secondary aim of the project was to create or modify debarking blades or an extra debarking device, which could effectively remove bark during normal harvesting operations. The purpose was to find solutions in order to remove 30–50% of the bark from logs during normal harvesting without any additional work phases. Debarking field tests were carried out in Finland and different harvester head devices were tested with alder, pine and birch.

3 Materials and methods

3.1 Drying trials sites

The changes in moisture content of roundwood ranging from 5 cm to 25 cm using different treatments were tested in four separate drying trials, located in Finland, Italy and Scotland. In each trial, wood piles were set up of wood from species commonly used for bioenergy purposes in the areas studied. The test sites were located in Sotkamo, Finland (Lat. 64.19 N, Long. 28.36 E), Cappella Maggiore, Italy (Lat. 45.98 N, Long. 12.33 E), Glenlivet, UK (Lat. 57.28, Long. 3.43 W) and on the Isle of Skye, UK (Lat. 57.13, Long. 5.83 W).

In the Sotkamo, Glenlivet and Cappella Maggiore trials, the effect of debarking and covering on the drying of the wood was tested. For each species studied, a control pile and a pile with wood that was debarked was set up. In Sotkamo and Glenlivet after the summer drying period, each pile was split in half and one of the halves was covered using plastic in the case of Sotkamo and paper fabric in the case of Glenlivet. In Cappella Maggiore all piles were covered from the beginning of the trial. On the Isle of Skye trial only covering of the wood was investigated and as a result one control pile and one covered pile was set up.

In Finland, the species tested were Alder (*Alnus incana*) and Scots Pine (*Pinus sylvestris*). The trees for the control piles were harvested using a conventional cut to length (CTL) harvesting system. Trees for the debarked piles were harvested with a modified harvester head that used different methods to remove bark. The harvesting of timber and establishment of the stacks was done in March in order to simulate an ordinary harvesting setup and to avoid too heavy debarking due to heavy sap flow. The size of stacks was approximately 5-6 solid-m3. The piles were located in an open area representing normal storage practices.

Figure 1. Location of the trial sites in Finland, Italy and Scotland.

In Scotland, the drying trials were established at two different sites: at the Glenlivet estate in Central Scotland and on the Isle of Skye in the North-Western part of Scotland. In the Glenlivet trial, the species tested were Sitka Spruce (*Picea sitkenses*) and Lodgepole Pine (*Pinus contorta*), whereas in Skye, only Sitka Spruce (*Picea sitkenses*) was tested. On both sites the timber harvesting was done using a conventional CTL harvesting system. Debarking for the Glenlivet site was carried out using a conventional harvester head. However, in order to simulate higher bark losses, the harvester operator stroked the stem 2–3 times more than normally through the harvester head. Timber was harvested in May 2007. The actual piles were established in June 2007. Pile size was about 4–5 m^3 solid.

In Italy, the trials were located Cappella Maggiore, in the Treviso province. The village Cappella Maggiore is placed in the Pre-Alps at an altitude of 150 m above sea level. Piles were located in an open area on wood log bearers. The species investigated for the test were Norway Spruce (*Picea abies*) and Beech (*Fagus sylvatica*). Stems derived from a thinning operation were piled into about 4–5 m^3 solid large piles. The debarking was made with a processor, stroking stems forth and back 2–3 times in the processing equipment. The trials were established in December 2007.

An overview of the different drying trial setups is given in Figure 2.

Figure 2. Design of the log piles in the different trials. a) Glenlivet (Scotland), b) Skye (Scotland), c) Cappella Maggiore (Italy) d) Sotkamo (Finland).

3.2 Sampling Methods

In Sotkamo and Glenlivet two different sampling methods to track moisture content were used. The first one was to weigh the entire piles using scales to measure the weight of trucks. The second method used was direct moisture samples to determine the dry weight of the material. This was also the method used to determine the initial moisture content in all sites right after the felling of the trees. In the Isle of Skye trial only direct moisture samples were taken.

The moisture content of green weight was defined according to the formula:

$$MC = 100 \times \frac{Ww - Wd}{Ww} \qquad \text{Eq 1}$$

where MC is the moisture content, Ww is the wet weight of the sample, and Wd is the dry weight.

Sample discs were taken by chainsaw with a thickness ranging from 2–3 cm. Each sample disc was taken at least 20 cm from the log end. The fresh sample disc were sealed in plastic bags and weighed in a laboratory setting. The weight of the sample-disks was measured before the drying was done according to the CEN standard CEN/TS 14774 (CEN, 2004). The dry weight of the samples was measured after oven-drying and the moisture content was then calculated. The sample was considered to be dry when the weight of the sample remains stable within a two day interval.

In Sotkamo and Glenlivet, the measurements made during 2007 were based on changes in the total piles' weight. The scales were located in turns in two of the corners of the piles. The total weight of the piles was then calculated and compared to the estimated dry weight of the piles. The measurements taken during 2008 were based on direct moisture measurements.

In the Cappella Maggiore trial the piles were divided into 5–7 sample loads with a maximum weight lower than the scale capacity (1500 kg). Sample loads were bundles of 7–10 stems tied up with iron strips (Figure 3).

The tool used for weighing was a device scale applied to the end of a crane. Weighing of piles was done measuring single bundles and repositioning them in the original place. Two iron chains were attached to the scale and their end was attached to the iron strips. When the crane lifted the pile, the weight was displayed on the device (Figure 4). During the test piles were weighted seven times, approximately every four weeks. The scale precision was to the kilogram.

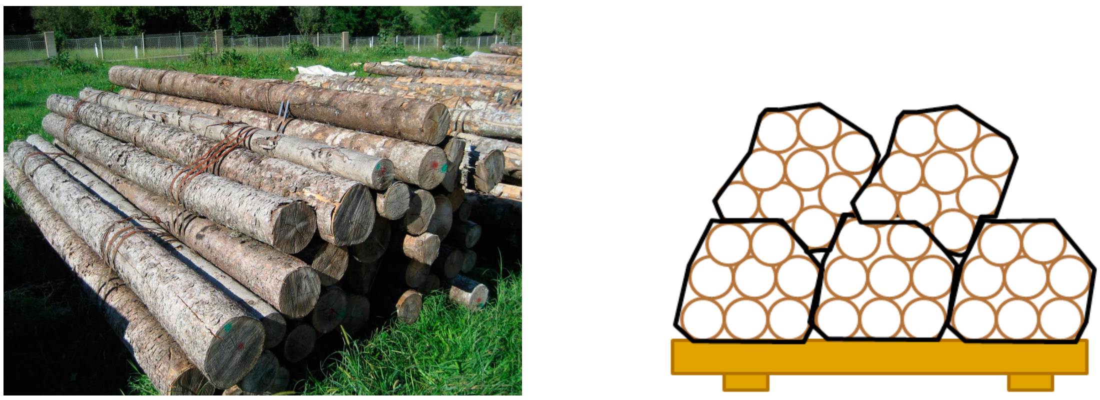


Figure 3. Picture and representation of the piles.

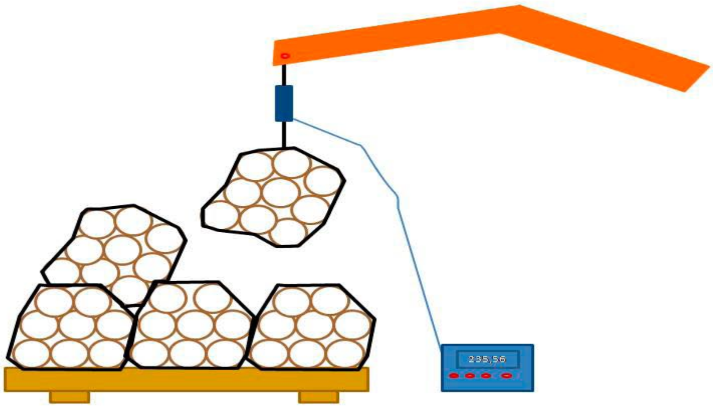


Figure 4. Representation of the weighting system

3.3 Debarking percentage

The percentage debarked stems was measured from photographs taken from the stems. The pictures were taken with a digital camera and analyzed with computer software that calculated the area of bark losses.

3.4 Analysis of weather conditions during the wood storage

Natural drying depends significantly on the local weather conditions. Therefore, weather records were collected from the closest meteorological stations to the trial locations. Furthermore, the results were compared to the 30 years average at the same location, in order to identify unusual meteorological events in the area. The stations selected were Kajaani Paltaniemi (Lat. 64.17 N, Long. 27.38 E), Vittorio Veneto (Lat. 45.97 N, Long. 12.30 E), Braemar (Lat 57.00 N, Long. 3.40 E) and Tiree (Lat. 56.50 N, Long. 6.90 W). The averages for the period 1960–1990 were based on the climate records provided by the WorldClim database.

3.5 Analysis of the drying curves

The moisture samples taken from the piles were used to analyse the evolution of drying in every pile. The resulting drying curves were first evaluated qualitatively by observing the changes in the moisture content of the piles. In order to analyse the overall effect of the treatments applied during the drying season, a linear regression model was applied, allowing for different slopes according to the treatments, and different intersections according to the different species and locations. The drying season was considered to last until September in Sotkamo (Finland), October in Glenlivet (Scotland) and November in Skye (Scotland), including these months. In Italy, all available records were included. The effects of the treatments during the winter were also analysed by comparing the moisture values after the winter with their corresponding values in the end of the drying season.

4 Results

4.1 Debarking percentage

In Finland, the removed bark area varied from 18–38% (average 29.5%) for alder and from 11–25% (average 19.2%) for pine. For alder, the results showed that the removal of bark is vital in order to promote drying. The results are very different with pine since the removal of bark had no significant effect on the drying process (Figure 8). The reason for this could be that when the timber is debarked the sap somehow hinders moisture loss. Nevertheless, in comparison to partially debarked or unbarked pine, unbarked alder dried considerably slower.

Bark loss was comparatively high in Glenlivet (Figure 5) most likely due to climate factors and the repeated handling of logs during the trials. It was noted that some of the tree stems had lost their bark completely over the course of the study.

In Cappella Maggiore the trials revealed that spruce and particularly beech lost a large share of the bark naturally when the stacks were not covered. It was found that the debarking percentage is higher on the surface of the pile likely due to the wear and tear effect of climatic factors. For beech, the debarking with a harvester head was efficient but for spruce the bark loss was only approximately 12% of the bark area (Figure 6). It is notable that in Italian conditions, the debarking intensity did not seem to promote the drying process in beech (Figure 8).

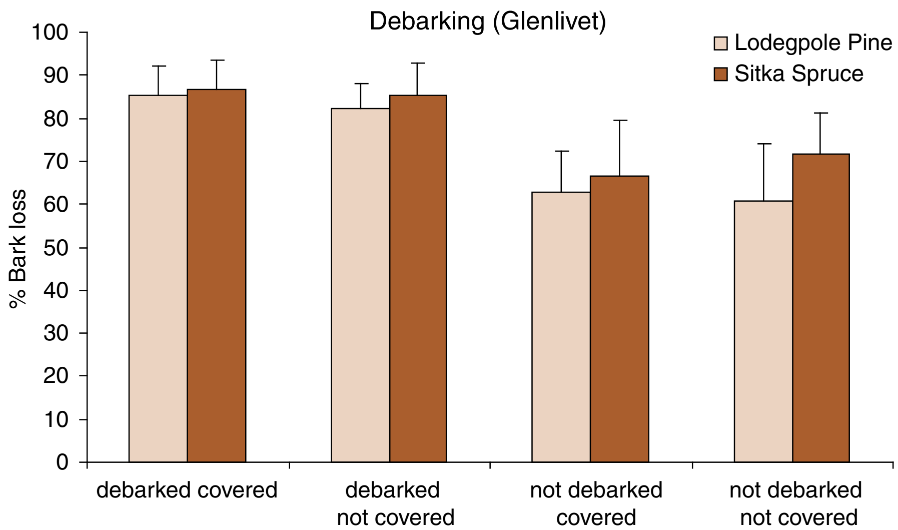


Figure 5. Debarking percentage in Glenlivet for sitka spruce and logepole pine.

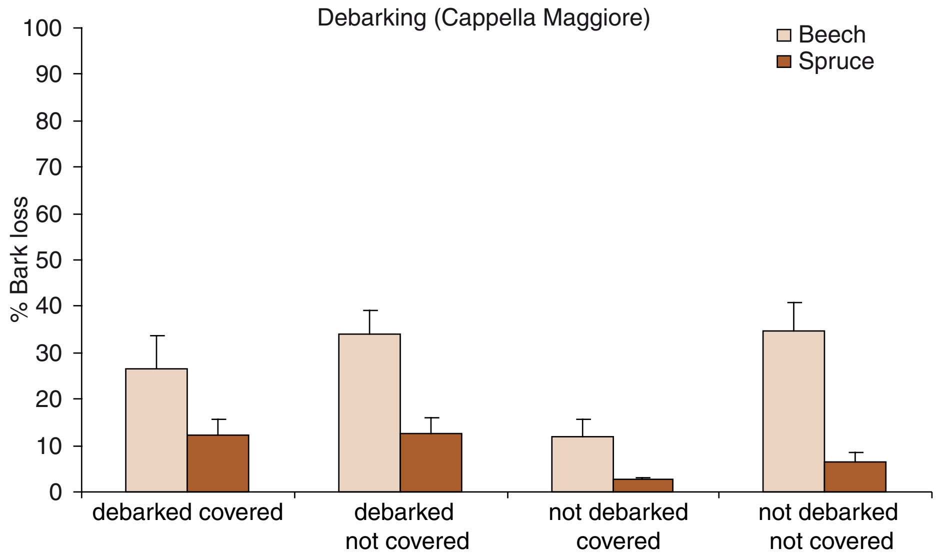


Figure 6. Debarking percentages in Italy, for Beech and Spruce.

4.2 Analysis of weather conditions

In general, the temperatures of the trial sites during the time of the study were similar to the 30 year average (Figure 7). In Finland, the maximum temperatures indicated a warmer winter than the 30 years trend, whereas in Italy the minimum temperatures where also higher than the trend.

Considering precipitation, the summer of 2007 in Sotkamo and the winter in Glenlivet were exceptionally rainy. The overall deviations of the 30-year average were, however, higher in the Finnish trial (Table 1).

Table 1. Precipitation during the period studied in the different trials.

Station	P acc, mm	P acc, mm (30-year average)	Difference	
Kajaani (Finland)	705.40	530.00	175.40	33%
Vittorio Veneto (Italy)	874.60	727.00	147.60	20%
Braemar (Scotland)	738.00	649.00	89.00	14%
Tiree (Scotland)	825.40	960.00	-134.60	-14%

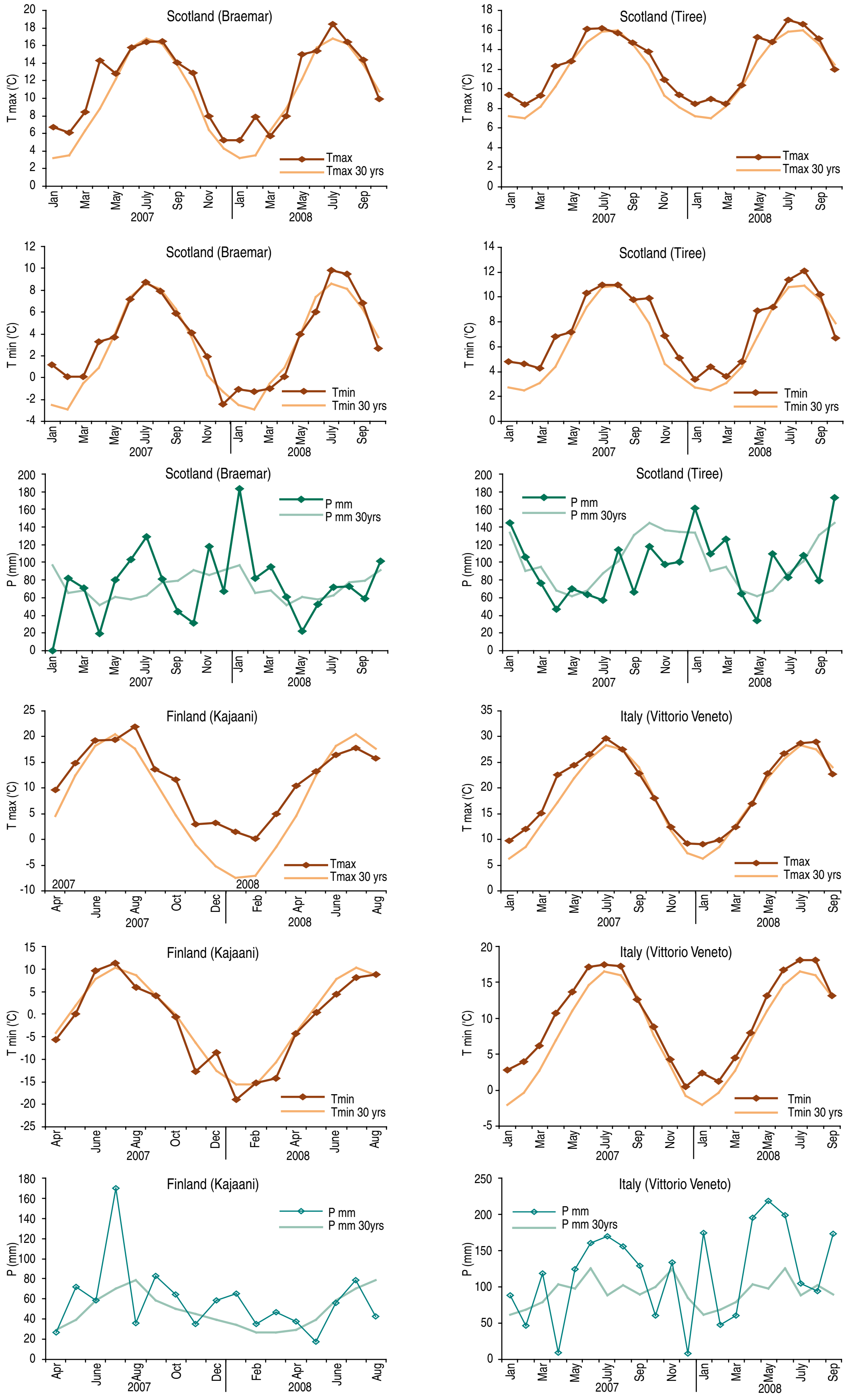


Figure 7. Meteorological characteristics of the trial areas.

4.3 Changes in moisture contents

The results of the moisture samples along time are shown in Figure 8. There were broad differences between the different geographical locations and the different species studied.

On the Isle of Skye the average moisture content of the timber after felling was 57%. The drying ratio was estimated to be 4%-units per month from May to November 2008 but during the winter 2008 stems actually gained moisture again (approximately 5%) despite the fact that the stacks were covered. On the Isle of Skye there was no obvious difference between covered or uncovered piles.

In the Glenlivet trial it was shown that the drying of timber can be efficient particularly during the spring and summer. Timber dried very effectively from June 2007 to February 2008. Unbarked and debarked Sitka spruce logs lost approximately 25% -units (from 55% to 30%) of moisture when the stacks were covered. Stacks which were not covered dried out slowly and uncovered lodgepole pine in particular gained moisture during the rainy period in the winter. After seven months drying uncovered lodge pole pine's moisture content was only slightly lower compared to the moisture content of fresh lodge pole pine (Figure 8).

In Finland, the drying of both pine and alder was very effective during the summer month and the moisture content was decreased from 53% to between 30% and 40%. Furthermore, covering of the piles in Finland had a significant effect on the drying process. Figure 3 indicates that the moisture content continued to decrease in covered piles after the cover was set up in September 2007 whereas moisture contents increased again in the uncovered piles.

The results also show that the cover effect was not so important in Italy for beech and spruce compared to Scotland and Finland. Comparing different procedures with beech there seem to be no significant difference in moisture content whether piles were covered or not or whether stems were debarked or not Figure 8. The moisture content of spruce was decreasing most vigorously when stems were debarked and piles covered, this method was the most efficient way to lose moisture. Otherwise there seemed to be no significant variance between different methods with spruce. The reason for this could be the same as with pine when the trunk is debarked the sap somehow hinders moisture loss.

Due to the rather small size of the stacks only one average moisture percentage was defined per pile. The results indicate that the moisture content in covered piles was more uniform within the pile when compared to piles which were not covered. The cover used in Sotkamo's trial was made of plastic and the trials showed that the plastic cover was not optimal since mold was found to be growing under all of the plastic covers. However, the growth of mold did not seem to affect the drying process considerably.

However, the effect showed notable differences according to the location of the species. In Finland, where the piles were not covered during the summer, the debarking method seemed to accelerate the drying of the alder pile, while did not affect pine. In Italy and Scotland, the piles both covered and debarked lost more moisture than the other alternatives, with the exception of the lodgepole pine, in Glenlivet.

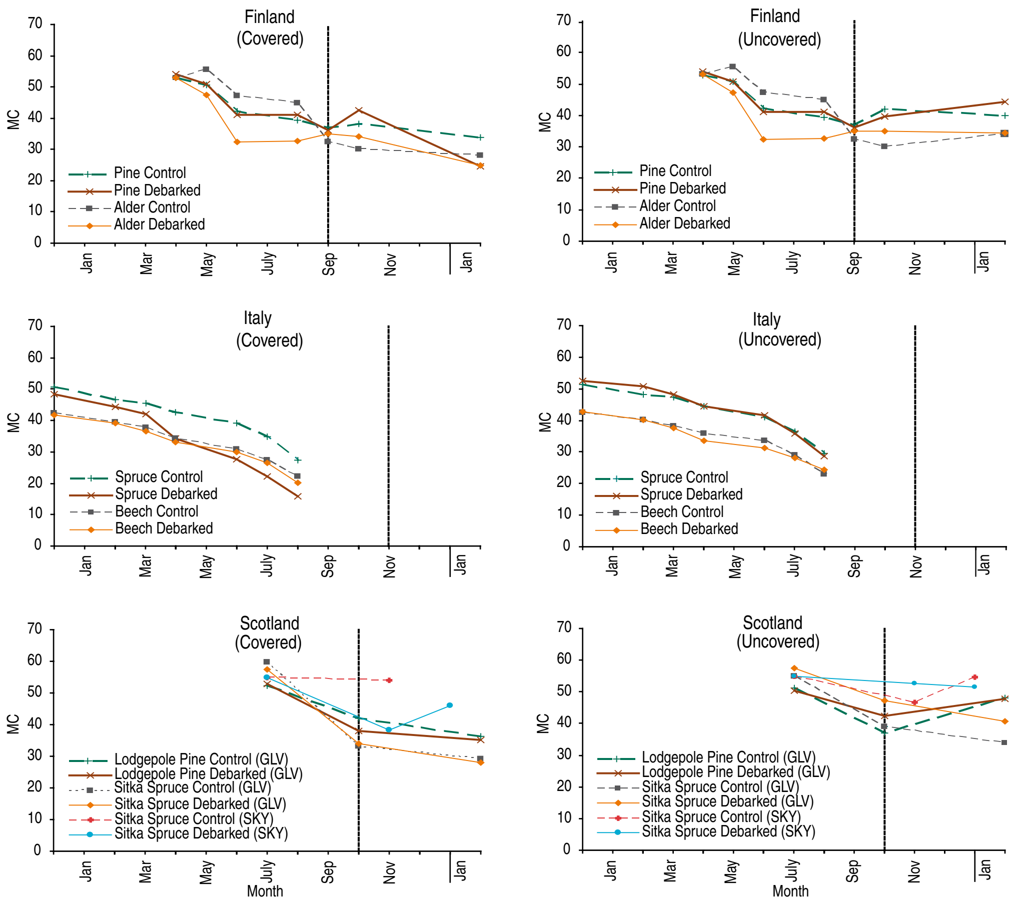
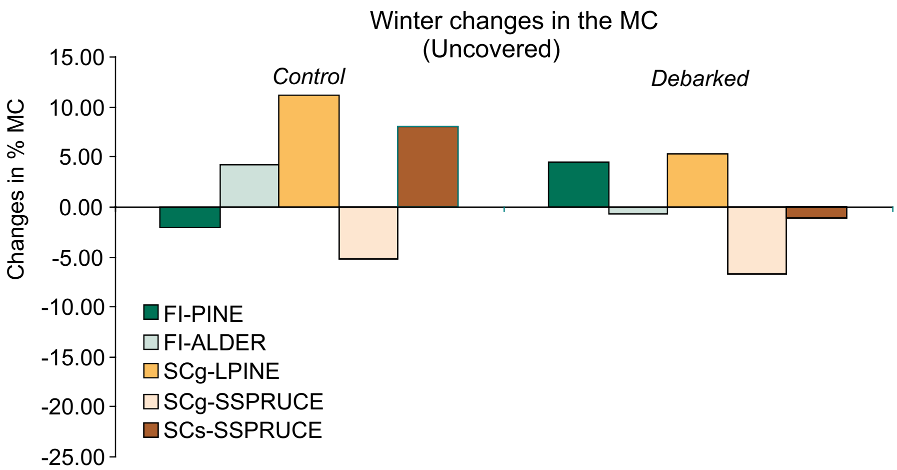


Figure 8. Changes in the moisture content of the wood piles in the different trials under different treatments. GLV: Glenlivet trial. SKY: Skye trial.

4.4 Winter changes

The cover applied to the piles seemed to affect the drying processes during the winter, preventing the water from reaching the logs. The piles uncovered showed higher levels of moisture content after the winter than during the end of the drying season. However, also in this case important differences were observed between the species tested. In reference to the debarking method itself, the piles debarked and covered lost more moisture in the Finnish trial, whereas no clear pattern was observed in Glenlivet, and the opposite trend was observed in Skye (Figure 9).

Attending to the moisture levels inside the piles during the winter, a clear gradient of moisture was observed in the uncovered piles, with higher levels in the logs located closed to the surface, and lower values in the bottom. The covered piles showed more homogeneous values of moisture content, regardless of the position of the log within the pile (Figure 10).



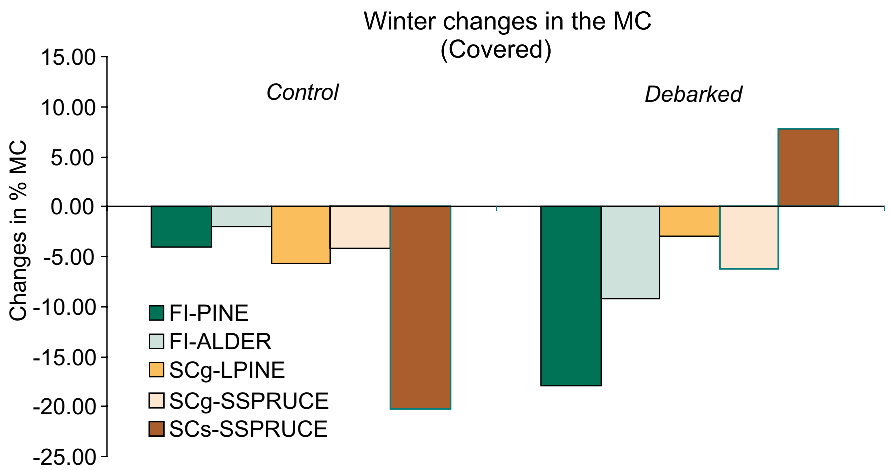


Figure 9. Absolute changes in the moisture content (MC) during the winter period, for uncovered and covered piles and two debarking treatments. FI: Sotkamo trial (Finland), SCg: Glenlivet trial (Scotland), SCs: Skye trial (Scotland), LPINE: Lodgepole pine, SSPRUCE: Sitka Spruce. In Sotkamo and Glenlivet, the changes are calculated for the period Oct-Feb, and in Skye, for the period Nov-Jan.

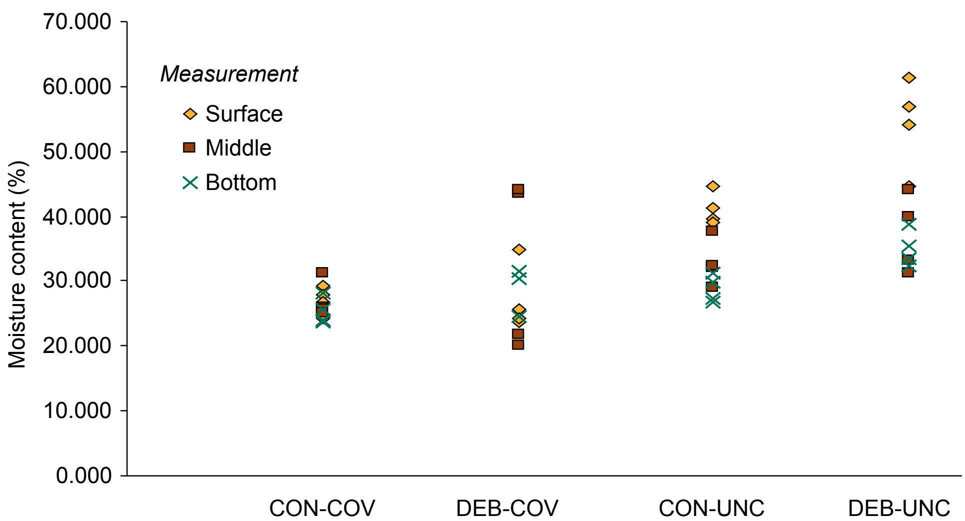


Figure 10. Differences in the moisture content according to the position of the logs in the pile. Data refers to the Sotkamo (Finland) trial, during the month of February, 2008.

5 Discussion

The results of this study have shown that natural drying is an effective method to enhance the energy efficiency of wood based fuel products in all regions studied. Furthermore, by adapting current harvesting methods and storage procedures even better results can be achieved. In addition, the results also indicate that broad leaved trees dry more effectively, if some partial debarking is carried out. In Finland, for example, debarked broad leaved trees dried out approximately 3% -unit/month more than non debarked stems during the most efficient drying season from April to June.

Under Scottish conditions, the results indicated that Sitka spruce dries well when it is covered. On the other hand, lodgepole pine does not dry out as effectively as spruce and during the winter rains lodge pole pine actually gathers moisture back, particularly if uncovered. Covering was found to be more important under Scottish conditions but nevertheless it has shown to be an effective method to reduce moisture in all of the trials, as had been shown also in earlier studies (Pettersson & Nordfjell 2007, Nurmi & Hillebrand 2007, Jirjis 1995, Lehtikangas & Jirjis 1993, 1995, Uusvaara, 1984, Heiskanen 1961).

It was found that the type of cover is also vital, and the trial has shown that paper based covers are more beneficial than plastic based covers, since the plastic based covers promoted the growth of fungi in the top layer of the pile. In some cases the cover was too small to cover the entire stack and therefore part of the stems were exposed to rain. This was unfortunate because trees will not only loose moisture more efficiently through the ends where wood itself has been exposed but also absorb humidity back more easily. Diameters of the stems were not known but it can be assumed that the larger the diameter the more time it takes to dry out. Therefore the drying time could be even shorter for smaller diameter stems and drying could be more effective as well. As a result the careful covering of the piles should be ensured particularly when roundwood is being dried.

Similar to Scotland, pine in Finland dries less effective when compared to broad leaved trees or spruce. One explanation could be the increased sap production in areas where the bark has been removed, but further studies would be needed to determine the exact cause.

The results of the trials showed that Scotland's climate seems to be suitable for natural drying of stems, when the piles are properly covered. This was also shown in earlier studies by Webster 82006) and Hudson et al. (2003). The results also confirm the conclusion by Nurmi and Hillebrand (2007) that the timber will lose moisture in Northern latitudes if conditions are favourable. In Italy the climate seems to be very favourable for the drying of timber and the best results were achieved in the Italian trial.

The moisture in the different parts of the piles measured varied significantly, especially when the piles where not covered, establishing a decreasing gradient from the top to the bottom. This phenomenon of large variations within the pile itself has also been noted by Heiskanen (1961). Further studies to determine the exact cause and methods to prevent that are needed to make the drying of the more moist areas in the pile more effective.

The study also revealed that the partial debarking of pine partly had no significant effect on drying. One reason for this might be that the debarked surface is contaminated with resin which will decrease the drying effect. Further research would be needed to investigate the exact cause of this in the future.

It was also noted during the study that practically in Glenlivet and Cappella Maggiorethe bark loss was high very high mostly due to climate factors and the fact that stems were shifted several times during the trials. Some of the stems had even lost their bark competely. This raises the question, whether debarking in these climatic conditions is needed.

Even though some of the facts presented in this study can be too specific to make general assumption on the drying processes, the main trends observed are similar to previous studies in Finland and Scotland (Pettersson & Nordfjell 2007, Nurmi & Hillebrand 2007, Jirjis 1995, Uusvaara, 1984, Lehtikangas & Jirjis 1993, 1995, Hudson et al. 2003, Webster 2008).

In the analysis of the debarking percentages some of the pictures were only taken from the surface logs of the pile. In this case it is not known what the debarking percent is inside the pile. It has to be assumed that the debarking percentage on the outside is higher compared to the inside due to a higher exposure to the sun. The bark loss was calculated when the trial was already coming to its end and therefore it is difficult to say how much of the bark was removed in the beginning and how much of the bark was lost during the weighting procedure during the trial.Furthermore, the images of the stems were not rectified to plane which might have caused some error in the evaluation of the debarking percentages. However, it was assumed that the used methodology would not have any significant effect on the overall results of the debarking analysis.

The study had to deal with a large number of technical difficulties in regards to the set-up of the trials and the different methods to follow the moisture content. As a result, some of the error of the data presented in this study had to be considered during the data analysis. However, the general trends are clear and some important findings have been discovered during the study. In the future, a more suitable setup of drying trials has to be found in order to guarantee the reliability of the results. New technologies are becoming available on the wood energy sector all the time and there is a clear need for simple to use tools to follow the moisture content of energy wood more effortless in the future.

From the energy plant manager's point of view, a model to follow the moisture content of energywood piles would a very helpful too. In this study, the availability of data largely restricted the possibilities of performing a model for moisture changes that could be generally applied. Therefore, in the future, more research and the establishment of a database of existing trials are needed in order to create a model to predict moisture changes in piles for practicioners.

The results show that the cover effect was not so important in Italy for beech and spruce compared to Scotland and Finland. Comparing different procedures with beech there seem to be no significant difference in moisture content whether piles were covered or not or whether stems were debarked or not Figure 8. The moisture content of spruce was decreasing most vigorously when stems were debarked and piles covered, this method was the most efficient way to lose moisture. Otherwise there seemed to be no significant variance between different methods with spruce. The reason for this could be the same as with pine when the trunk is debarked the sap somehow hinders moisture loss.

6 Conclusions

This study focused on the development of effective working methods to promote the drying of small roundwood for energy purposes. Although there are evident limitations in the direct extrapolation of the results, the conclusions of this study show that natural drying of wood can be achieved rather easy with only minor changes to existing practices. The study has clearly shown that covering of piles is of utmost importance in Scotland and Finland. The partial removal of bark has also had positive effects on the drying rate. Both of these operations do not have any significant effect on the total procurement costs to produce high quality chips, but offer simple to use solutions with large impacts.

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