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Birch As Sawn Timber and in Mechanical Further Processing in Finland. A Literature Study

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Abstract

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This study based on literature and restricted interviews of forest products companies is a compilation of current knowledge concerning utilisation of the wood of birch species growing in Finland, silver birch (*Betula pendula)* and pubescent birch (*B. pubescens*), for saw milling and further related processing. As the basis for this, the properties (morphological, anatomical, physical, mechanical and chemical) of birch wood are presented as well as the effects of cultivation and how growing conditions affect these properties. The issues cover resources and use of large- and small-dimensioned birch, current and potential importance of birch for saw milling as well as for furniture and joinery industries, quality and specific properties of birch timber for sawing and processing for special purposes, principles and methods of grading the quality of wood, how to improve and control quality, timber procurement, primary processing, machining and surfacing as well as semi- and end-products. Based on the available data, the principal needs for research and development to increase utilisation of birch and improve its effectiveness are presented.

Keywords *Betula*, mechanical processing, saw milling, utilisation, properties, resources
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1 Introduction

Birch is a traditional and well-known material for mechanical wood processing in Finland. In addition to its use as plywood and veneer, birch timber has also been used in carpentry, although the amount of birch timber used in joinery and carpentry is small compared to Scots pine. This is due mainly to the fact that birch seldom grows as pure stands with possibilities to cut large amounts of raw material at a time. Another reason for this are defects in the trunks, which markedly increase the amount of waste wood. On the other hand, sound birch wood is very suitable even for products of carpentry, which demand high quality wood. After the birch loss in the 1950's and 1960's, possibilities to cut birch timber increased, and since then the use of birch timber became more popular (e.g. Kärkkäinen 1998). Birch has also become a research object in wood science and technology as the properties of its wood and their improvement have now begun to interest researchers due to increasing use and quality demands. The cultivation of trees, primary processing of timber and grading rules related to the quality of the end-product have been developed.

Quality requirements, determined by the purpose for which the wood will be used, should be taken into account as early as when birch cultivation or forest renewal is planned, because different uses set different demands for the timber. In practice this does not occur, however, and defects in the quality of birch sawn timber cause problems for the industry that uses birch wood (e.g. Kataikko 1996). Log-size trunks of good quality are always in demand. Small trees – which usually have no decay or defects, which otherwise are common in birch – may also have a potential for use in birch sawing. They could be sawn into billets; Koivisto (1958a) claimed as early as 1958 that for the future of birch use in the mechanical wood industry, small-dimensioned birch is important. Both now and in the future, there are good possibilities to increase the market demand for birch sawn timber and for components made of birch, especially as exports.

The purpose of this review is to compile those facts that are important for the use of birch as sawn timber. These facts include resources, balance of forests, cutting possibilities in Finland, extent of the carpentry and furniture industry based on the sawing and use of birch timber, markets and economic significance, special properties of birch from the viewpoint of the industry processing it, grading and requirements for the quality of birch timber, possibilities to improve the properties, development of the procurement of birch timber (felling, storage, transport), primary processing of logs and sawn timber (sawing, drying) and possibilities to develop the machinery and methods for all phases of handling birch timber.

The knowledge of especially sawing and further processing is mainly based on experiences of persons working at the industries concerning these fields. Thus, in addition to the scientific articles, other articles and interviews of persons connected to the industry have been taken into account.

2 Resources, Timber Balance and Possibilities to Cut Birch Wood

2.1 Resources

The birch resources in Finland have changed only slightly during the 20th century. Since the First National Forest Inventory (1921–1924) the birch resources have remained between 224 and 295 million m^3 (Kärkkäinen 1998). The common conception that the birch resources, and especially future cutting possibilities, were almost destroyed during the 1950's and 1960's, when birch was cleared out of the way of conifers because there was no significant industrial use for it, is unsupported. At present birch makes up 14.6% of the total volume of the standing crop in southern Finland and 16.1% in northern Finland (Sevola 1996). According to this, the total volume of birch resources in southern Finland is ca. 195 million m^3 (Table 1, Louna and Valkonen 1995).

According to the Eighth National Forest Inventory (1986–94), there are in southern Finland ca. 0.84 million ha (7.3%) and in northern Finland 0.67 million ha (7.8%) of birch-dominated forests (Table 2, Sevola 1996). The actual importance of birch for forestry is, however, greater than the area indicates, because an important proportion of birch is growing in forests dominated by other species. On the other hand, the general nature of birch to grow as a minority species in individual stands makes its procurement often difficult, both from the aspects of logging technology and timber marketing. The ditching of peatland forests, clear cuttings and tilling of soil have favoured birches in mixed forests (e.g. Heikurainen 1959, Yli-Vakkuri 1961, Appelroth et al. 1971, Mielikäinen 1980, 1985).

The volume of log-size deciduous trees is markedly smaller than that of conifers, because the common minimum requirements for dimensions are more strict and the proportion of the trunk that is not good enough for saw or veneer logs is larger in birch than in conifers, 40–60% and 5–20%, respectively (e.g. Kärkkäinen 1984, 1986). In this respect, significant differences can be observed between the two Finnish birch species, *Betula pendula* Roth and *B. pubescens* Ehrh.: the proportion of saw timber of the volume of *B. pendula* in southern Finland is 30% but that of *B. pubescens* is only 10%. Thus in southern Finland, 1.4 times more logs of *B. pendula* could be obtained than logs of *B. pubescens* (Table 1).

The proportion of large birches has not diminished; on the contrary, the birch standing crop of over 30 cm diameter at breast height is at present even larger than in the 1930's and double the amount at the beginning of the 1950's (Kärkkäinen 1998). According to Verkasalo (1997b, calculated from the results of Kohmo (1984)), about 80% of the total 13 million m^3 of *B. pubescen*s logs in southern part of Finland

Table 1. Resources of *Betula pendula* and *B. pubescens* according to the Eighth National Forest Inventory in Finland 1986–94 (Louna and Valkonen 1995).

Timber assortment	*Betula pendula*	*Betula pubescens*	Total
		1000 m^3	
Log	15 828	11 193	27 021
Pulpwood	36 877	96 731	133 608
Total	52 705	107 924	160 629
Log-%	30.0	10.4	18.0

Table 2. Forests of mineral soils dominated by *Betula pendula* and *B. pubescens* in southern and northern Finland according to the Eighth National Forest Inventory 1986–94 (Sevola 1996).

	Area, 1000 ha		Areal proportion, %	
	B. pendula	*B. pubescens*	*B. pendula*	*B. pubescens*
Southern Finland	253.0	586.4	2.2	5.1
Northern Finland	8.5	657.0	0.1	7.7
Total	261.5	1243.4	1.3	6.2

are smaller than 30 cm in diameter. Logs of *B. pendula* (total of 21 million m^3) are distributed more evenly by diameter class; e.g. the proportion of logs with a diameter over 30 cm is 40%. In this case the proportion of saw timber of the whole log-size crop is, on average, only 38% for *B. pubescens* but 54% for *B. pendula*, and for larger diameter classes the difference increases.

The abundance ratio of birch species in different parts of Finland can be assumed to develop as mentioned above, even though the planted *B. pendula* stands in Finland are mostly located in the eastern south Finland. If the present trend toward natural regeneration of forests and minimising of treatment of seedling stands continues, both birch species will probably become more common in mixed forests. The requirements for maintaining the landscape and sustaining the diversity of forests also lead to an increase in the overall proportion of birch.

2.2 Timber Balance and Cutting Possibilities

Of the total growth of deciduous trees in Finland, the proportion of birch growth is estimated to be 85–90% (Louna and Valkonen 1995, Sevola 1996). Until the beginning of the 1970's the growth of deciduous trees remained almost constant in southern Finland and decreased in northern Finland. This was evidently due to the previous conscious reduction of deciduous trees, although this reduction was decreased when forest improvement gained momentum in the 1960's. Forest improvement is also the most important reason for the increase in growth after that; the cutting potential for birch increased by 3.4 and 1.4 million m^3 per year in southern and northern Finland, respectively. The increase in growth occurred nation-wide mainly in the 1970's but continued in southern Finland for the following 15 years. In northern Finland it has remained constant for the last 15 years, which is due mainly to the ageing of birch stands and reduction in forest improvement (Sevola 1996).

The proportion of birch of the total drain of deciduous trees in Finland is estimated to be 90–95% (Louna and Valkonen 1995, Sevola 1996). In southern Finland, the drain of deciduous trees increased until the end of the 1960's, but during the next 10 years it decreased markedly, by 7 million m^3 per year. The reason for this was the significant decrease in the demand for firewood. After that the drain increased further because the demand for pulpwood increased by 0.5 million m^3 per year for ten years, but that demand decreased during the depression at the beginning of the 1990's. The drain of birch increased slightly until the middle of the 1970's, then decreased markedly and started to increase again at the beginning of the 1980's (Sevola 1996).

Until the middle of the 1970's, the timber balance in the deciduous forests of Finland, i.e. drain subtracted from growth, was clearly negative and after that was even more clearly positive. During those periods, the volume of deciduous trees decreased by 3.7 million m^3 and by 0.2 million m^3 per year, on average, in southern and northern Finland, respectively. Since then the resources of deciduous trees have grown by 3.9 million m^3 per year in southern Finland and by 1.2 million m^3 per year in northern Finland. From this it can be concluded that the cutting possibilities for deciduous trees are clearly improving (Sevola 1996).

Thus, according to the estimates by the MELA group of the Finnish Forest Research Institute (pers. comm.) during the 50-year prediction period, cuttings of saw and veneer logs of birch can be increased from the level at the beginning of the 1990's according to the instant cutting potential by 0.7 million m^3 per year and according to the maximum sustained yield by 0.9 million m^3 per year, respectively, when the cutting possibilities are compared to the situation in which there is no import, only domestic wood. The average cutting possibilities per year for saw and veneer logs during the same period are, according to the instant cutting potential, 1.9 million m^3 and, according to the maximum sustained yield, 2.1 million m^3 per year. The most extensive cuttings during the first 10-year period, 2.4 million m^3 per year, would first lead to halving of the cutting possibilities, but during the last 10-year period they would increase to the level that existed at the beginning of the first 10-year period. On the other hand, if the cuttings were done reasonably during the first 10-year period, i.e. 2.0 million m^3 per year, the cutting possibilities would be greater than the cutting potential during each of the following 10-year periods.

3 Use of Birch Wood and Its Present and Future Use As Sawn Timber

3.1 Purposes of Use in the Past and at Present

In Finland, sawing of birch probably started during the 1850's (e.g. Jalava 1949, Ronkanen 1968, Kärkkäinen 1991). The production increased rapidly until the 1920's, but since then the amounts of sawn birch have remained stable; the largest amount of logs, ca. 0.6 million m^3 per year, was sawn in the middle of the 1960's. The amount of sawn birch logs is presently 0.15–0.2 million m^3 per year, e.g 0.18 million m^3 in 1993, while at the same time their main user, plywood industry, used 0.87 million m^3 of birch (Pajuoja and Suihkonen 1994).

Sawing of deciduous trees is carried out by some specialised industrial family enterprises which are registered and monitored by the Finnish Industrial Statistics, and a heterogeneous group of small non-industrial saw mills. Their proportions of the production of hardwood sawn timber were 37% and 63% in 1993, for example (Pajuoja and Suihkonen 1994). At present, small sawmills carry out more than half of the birch sawing in Finland (Sevola 1996). However, the proportion of birch of the total timber used by the small saw mills was only 6% in 1990 (comp. other hardwoods 1%). – The Finnish Industrial Statistics covers the sawmills with five employees, annual turnover of more than FIM 3.5 million, or use of roundwood of more than 10 000 m^3 per year, at their minimums.

Birch wood has been used in Finland for industrial products since the middle of the 19th century. The first industrial use was manufacturing reels of thread, which began in 1873 (e.g. Jalava 1949, Ronkanen 1968, Kärkkäinen 1991), and in the 1920's and 1930's about 80% of the demand for reels of thread for whole the world was supplied by Finland. In this industry, however, wood was not used efficiently; recovery of ready reels was only 12% of the wood used.

The development of the plywood industry significantly increased the use of birch wood. Wiikari Oy, Karkku in West-Central Finland, started rotary-cutting of veneer in 1894 by producing birch plywood and from this e.g. chairs and chests of drawers (e.g. Jalava 1949, Ronkanen 1968, Kärkkäinen 1991). The first large plywood factory was founded by Wilhelm Schauman Ltd. in 1912 in Jyväskylä, and since 1918 the amount of birch used in the plywood industry has been larger than in sawing. After that the industry developed considerably and Finnish plywood dominated in the global markets for plywood made of deciduous trees. The Second World War and the loss of four plywood factories to the Soviet Union caused a temporary decline in the Finnish plywood production.

In the 1990's the use of birch wood in the plywood industry has been, on average, 1–1.5 million m^3 per year (Sevola 1996, Mikkola 1997). The peak use, 2 million m^3 per year, was reached in the middle of the 1960's, as was in sawing (e.g. Kärkkäinen 1991). After that the lack of birch raw material and competition from the new plywood producers in south-eastern Asia caused a crisis in veneer and plywood manufacture in Finland. As a result, the Finnish plywood industry had to specialise in expensive special products and also start to use large amounts of Norway spruce (*Picea abies*) as inner veneers in plywoods, where the properties and price of the product were determined by the outer birch veneers (Juvonen and Kariniemi 1984, Koponen 1995). Import of birch from Russia and Baltic countries for veneer cutting has increased during recent years. According to information provided by the industry, 15–20% of all the birch used in Finland, i.e. ca. 0.15 million m^3 per year, is imported (Kautonen, Pitkänen, pers. comm.). Also large birch logs were imported earlier, mostly from Russia and Sweden, several tens of thousands of cubic metres per year, e.g. 75 100 m^3 in 1993 (Mikkola and Kulju 1994). At the same time, special-quality birch logs were exported, mostly into Germany, e.g. 7400 m^3 in 1993 (Saimovaara 1994). Import of birch for sawing from the east and south is also increasing continuously.

In addition to sawing and veneer and plywood manufacture, there are many special uses for log-size birch (e.g. Jalava 1949, Mali 1980, Salmi 1987a,b). The most valuable raw material for those logs are the special forms of *B. pendula*, masur (curly-grained) birch and flamy-grained birch. They are used for furniture and interior decoration as well as for decorative items. Ordinary birch wood is widely used for these purposes if it is of good quality, but it is also used for ice-cream sticks (Björken blir... 1989), ice-hockey sticks (Maila on... 1990) and musical instruments (Salmi 1987a,b). Matchboxes, skis, javelins, plywood for railway carriages, trams and aeroplanes as well as many utility articles have previously been manufactured from birch (Jalava 1949, Ronkanen 1968, Salmi 1987a,b).

The traditional use of small-dimensioned birch has been as firewood (Salmi 1987a,b). Its significance started to decrease rapidly during the 1950's, which caused problems in the demand for birch timber from thinnings. The present use of birch as firewood is estimated for ca. 2–4 million m^3 per year (Kärkkäinen 1991, Salakari and Peltola 1995).

Another use for small birch timber is pulping. As early as the 1920's attempts were made to use it for pulp (e.g. Levlin 1986, Kärkkäinen 1991), but not until the 1950's was a kraft pulping method for birch invented. After that in the middle of the 1970's, the use of birch in the pulp industry steadily increased to 4 million m^3 per year. The ability to use significant amounts of birch in the manufacturing of printing and writing papers has markedly increased the demand for birch pulpwood since the end of the 1980's. Thus at present the pulp industry is the most important consumer of birch in Finland, as it uses more than 10 million m^3 of birch per year (Sevola 1996).

Small-dimensioned birch has also been used in the fibre-board and particle-board industries (e.g. Liiri 1960, Kärkkäinen 1991). At present, however, the raw material of these industries is almost totally waste wood from sawmills and plywood factories.

3.2 Present Use of Sawn Birch Timber

The sawing of birch is concentrated to southeastern and central Finland. These sawmills carry out mainly special sawing for selected end-products, mostly for carpentry and especially for the furniture industry. The parquet industry also uses large amounts of birch timber of special dimensions (e.g. Elowsson 1989, Junckers Industrier... 1992, Verkasalo and Paukkonen 1997). During the 1980's, several tropical hardwoods became serious competitors for birch in these uses; e.g. keruing (*Dipterocarpus* spp.) from Malaysia and Indonesia, due to their markedly cheaper prices (Koivua vientiin... 1988). During the present decade the trend has changed because of the active environmental discussion. The most important competitor of birch in Europe is beech (*Fagus sylvatica*).

A significant proportion of sawn birch timber is exported. The proportion, however, clearly differs in individual sawmills, depending on the ownership of the mill (independent or belonging to a consolidated furniture corporation). For example, Vilkon Ltd., Hirvensalmi in the district of Southern Savo, exports about 25% of its production (Peltoranta, pers. comm.) while the private Hakkaraisen Saha, Viitasaari in the district of Central Finland, exports more than 70% of its production (Koivua vientiin... 1988). The main countries to which birch timber is exported are Sweden, United Kingdom and Germany. In 1993, 4400 m^3 of sawn birch timber was imported, but before 1987 the amount imported was insignificant (Louna and Valkonen 1995).

According to Kataikko (1996), furniture manufacturers buy birch timber fresh or only air-dried and as through-sawn; they then dry it themselves to a moisture content of 6–8%. The importance of the furniture and interior decoration industries is based on the fact that they use the best, and thus the most expensive, birch timber. The distribution of the tree species used by the furniture industry in 1993 is presented in Table 3. This distribution is based on an estimated total furniture-wood use of 90000 m^3 (see Saimovaara 1994: estimated total use 40000 m^3, according to a different branch classification). The proportion of wood processed in ways other than sawn is significant; the real amount, and especially distribution of the species, is very difficult to determine, as well.

Table 3. Tree species used by furniture industry as sawn timber in 1993 (Louna and Valkonen 1995).

Species	Chairs	Office furniture	Kitchen furniture	Other furniture	Total
			%		
Scots pine (*Pinus sylvestris*)	92.3	30.3	21.5	65.4	74.1
Norway pruce (*Picea abies*)	2.6	0.9	1.9	5.0	4.0
Silver birch (*Betula pendula*) and pubescent birch (*B. pubescens*)	3.3	24.0	18.3	27.5	19.4
Other domestic	0.7	8.5	15.4	0.6	0.7
Beech (*Fagus sylvatica*)	0.5	31.6	41.1	1.4	1.5
Other foreign	0.7	4.6	1.9	1.4	0.3

The raw materials used in the furniture industry can be roughly classified into framework materials (solid wood, particle board, MDF-board, others) and surface materials (cloth, leather, melamin, plastic, others). According to a questionnaire for furniture factories by Laaksonen and Rajala (1987), frameworks were made mostly of Scots pine (*Pinus sylvestris*) (36.0%) and particle board (31.4%); the proportion made up of birch was 26.4%. The proportion of birch veneers was not, however, separated from all the surface veneers. When this issue is looked at according to the number of employees in the factory, if the number of employees is below 20, the most important framework materials were Scots pine and particle board. In the factories with 20–49 employees, the most important materials were Scots pine (38%) and birch (34%); and in factories Scots pine with more than 50 employees the most important framework material was particle board (60%). According to region, particle board was the most important framework material in the Lahti area (40%), where most of the large furniture corporations are located; while in the district of small and medium-scale family enterprises of southern Pohjanmaa birch was also important. In other parts of Finland the most important raw material was Scots pine.

Masur (curly-grained) birch, a genetic modification of *B. pendula*, is important in carpentry and in the furniture industry. It is most common in the districts of Häme and Carelia (Hämet-Ahti et al. 1989). An important proportion of masur birch grows in the cultivated birch stands of the Finnish Forest Research Institute. Although there are no statistics on its use, the estimate for 1993 was a couple of hundred thousand kilograms for

Table 4. Tree species of timber used for the joinery industry in Finland in 1993 (Louna and Valkonen 1995) (parquet: the figures include both the surface lamellae and the foundation).

Species	Parquet	Doors and windows
	%	
Scots pine	0.2	82.5
Norway spruce	62.3	12.7
Birch	5.5	1.0
Oak (*Quercus* spp.), ash (*Fraxinus excelsior*), maple (*Acer* spp.)	20.3	2.7
Beech	9.4	1.0
Other species	2.3	0.1
Total, 1000 m^3	50	123

lathing and small items (Louna and Valkonen 1995). The most important uses for masur birch are veneer, knife handles and other decorative and practical items. A marked proportion of masur birch is exported as raw material, either sawn or veneer.

Flamy-grained birch is practically as commonly (or rarely) available as masur birch. Information about its occurrence and availability is very scanty; the factories meet it irregularly among the normal flow of birch logs. Flamy-grained birch is rarely sorted for special purposes in Finland. However, it is mostly sold to Germany as veneer, like some masur birch. It is said that small amounts are imported from Sweden for carpentry.

The use of birch in the joinery industry is rare, but it is commonly used as the surface lamellae of parquet for which purpose it is very well suited (Table 4). The joinery industry buys birch kiln-dried and cut to special dimensions, as sawn timber or billets (Louna and Valkonen 1995).

For construction, however, birch does not suit at all, because when the moisture content of the environment changes, birch wood decays easily (e.g. Farmer 1981). In addition, birch wood is relatively heavy, its strength in relation to its density is weak and its stability in form and dimensions is questionable both during further processing and *in-situ* use (e.g. Vesterinen 1956, Kärkkäinen 1984). In Norway, however, it has been tested for use as glulam bearers in a church with a long bearing distance; but no estimates of its long-term suitability can be made yet (Kučera, pers. comm.). American paper birch, *B. papyrifera*, has also been tested successfully as studs for buildings in northern America (Erickson et al. 1986, Larson et al. 1986, Verkasalo 1990).

3.3 Future of Birch As Sawn Timber

Because there are no comprehensive estimates of future use of birch timber, only rough estimates can be presented. Attempts are currently being made, however, to obtain competitive benefits by using cheaper aspen (*Populus tremula*) and alder (*Alnus glutinosa*, *A. incana*) sawn timbers instead of birch. This is because the supply of birch timber may be scarce in spite of growing resources, and the relative price of birch has risen (Kärki 1997).

The possibilities of birch are considered to be based on the characteristics of special timber from birch species. Tree species that occur in limited regions outside of their natural growing areas, which make up only a small proportion of the forest area and the growth per year, or the wood of which is exceptional either due to its structure or to its properties (e.g. masur and flame), can be classified as special timbers (Kärki 1997). Special sawn timber, on the other hand, can be of any species, if there is a certain purpose for its use, it has special dimensions or its use is minor.

The present extensive resources of birch in Finland would make it possible to use birch more than it is used today. The availability has, however, occasionally been a problem for sawmills and plywood factories (Juva and Ahtorinne 1995, Kärki 1997). Problems of availability have been partly due to the nature of birch to grow as a minority species in stands dominated by softwood species (Kärkkäinen 1984, Verkasalo 1997b). Accordingly, the supply of birch timber is closely linked to the demand for softwood timbers. Another cause for the problems is the great demand for birch from abroad (Juva and Ahtorinne 1995); almost all important industries that use birch in Finland use both imported and domestic birch. This is especially true in eastern Finland where mechanical processing of birch is very important, while e.g. in the districts of Central and Northern Pohjanmaa, Kainuu and Satakunta there is no marked mechanical use even for log-size birch trunks (Verkasalo 1997b). When manufacturing techniques as well as products develop, even birch 10 cm in diameter becomes important in sawing (e.g. Verkasalo 1998, Heräjärvi et al. 2000). For the mechanical wood processing, this could considerably increase the potential of birch from thinnings, in particular from first commercial thinnings which are currently an underutilised source of industrial wood.

There are great expectations for planted *B. pendula* stands. It is assumed that they will relieve the lack of log-size birch at the latest in the 2010's, and it is planned that 1/3 of the demand of the plywood industry will be supplied from these planted stands if the use of birch remains at its current level (Verkasalo 1997b,c). Raw material for sawing and its end-products should be also available from planted birch stands.

The large suppliers dominate the furniture markets, and their purchasing agents are important in determining wood preferences (Lahti 1991). Thus it can be assumed that also in the future the demand for birch sawn timber will depend on fashion. Birch is sometimes considered to be too light a furniture wood in Central Europe (Juva and Ahtorinne 1995). At present it seems that fashion is starting to favour light woods; e.g. in France beech is kept as light as possible because comsumers have started to require light furniture (Willman 1997). Birch is, however, easy to modify in colour, e.g. by staining, both artificially and naturally by steaming or drying in a hot climate; and so-called eco-darkening (Räuherbirke, Spalted Birch) could give birch very ecological status in Central Europe.

4 Grading of Birch Timber

4.1 Logs and Sawn Timber

The first summary of the quality requirements for birch saw logs and sawn timber in the furniture industry was presented by Jalava (1943). He claimed that even as early as the 1940's the quality of birch stands was poor, which seems to be a marked exaggeration compared to the current views. His claim may, however, be based on the fact that at the beginning of the century the plywood industry was used to getting excellent birch raw material.

On the other hand, Jalava (1943) thought that the furniture industry could also use poor quality birch timber to manufacture good quality products. That was, of course, at the cost of large amounts of waste wood. As furniture made of birch was not usually painted with a coating colour, defects could be seen on the finished product, thus decreasing its value. That is why also at that time the quality of timber was very important for furniture mills, too. As early as the 1930's every thickness of sawn birch timber for furniture had its own quality requirements because the different qualities were used for different purposes (Jalava 1943).

Since the beginning of the 1960's the commercial quality requirements for birch saw logs have been the same or slightly stricter than the dimension and quality requirements for veneer logs (see Heiskanen 1966, Salmi 1987a, Vanerikoivun... 1998, Koskinen, pers. comm., Kuitunen, pers. comm., comp. e.g. Ronkanen 1949). The properties that are stricter for saw logs are the diameter, straightness, and decay and surface defects, because the products should not contain any discoloured wood (Salmi 1987a). On the other hand, quite small-diameter and short logs (Ekström 1987, Heräjärvi 1999, Heräjärvi and Varis 2000, Heräjärvi et al. 2000, Harinen, pers. comm., Kuitunen, pers. comm.) and logs with thick but healthy knots may have been accepted for sawing (Heräjärvi 1999, Heräjärvi et al. 2000, Harinen, pers. comm., Kuitunen, pers. comm.). The technical properties of circular saws, however, prevent the sawing of very thick logs, and crook-sawing cannot be used for birch as much as for conifers, although it has been tried with a frame saw (Peltoranta, pers. comm.). Thus the defects in the log form are still an important factor causing waste wood in sawing. In particular, the quality for knottiness should be good; the parts of the trunk that include many knots should be avoided, and the knotless surface wood (Elowsson 1989) as well as wood from inner parts of trunks with sound knots (Harinen, pers. comm.) are in demand.

In practice, the commercial quality of birch veneer and evidently also of sawn timber is determined by the knottiness in more than 90% of all individual cases (e.g. Ronkanen 1949, Heiskanen 1966, Kärkkäinen 1984). Most attention is thus paid to decayed and dry knots. Their disadvantage is both aesthetic and practical: they loosen when dried and they also weaken the strength of the wood. Vertical knots are the most harmful because they are the largest and are very commonly the cause of core decay. Epicormic branches may develop on the surface of the trunk, and may thus cause defects in good quality surface wood. The epicormic branches may also be related to decay and decayed knots (Heiskanen 1957). In addition to knottiness, the quality of the sawn timber is degraded by surface defects, decay, insect damage, discoloration and crookedness of the trunk, which cause deviations in the fibre direction leading in turn to both aesthetic defects and weakened strength (Lappi-Seppälä 1933, Vaneritutkimuksia... 1937, Jalava 1938a, 1949, Lehonkoski 1937, 1949, Koivumäki 1962, Heiskanen 1966, Meriluoto 1966, Juvonen and Kariniemi 1984, Schulman 1989, Koponen 1995, see Sarvas 1944). The standards set by manufacturers of instruments, arms, boats and sports equipment are set separately for different items, but usually they are very high (Salmi 1987a,b, Kärki 1997).

According to Louna and Valkonen (1995), the quality requirements of sawmills are the same for both conifers and birch, and the requirements of sawmills that use special wood are also much the same (Kärki 1997). Some small entrepreneurs also use some low quality logs with a diameter of 14–20 cm and length of 1.5–3 m (Louna and Valkonen 1995, Harinen, pers. comm.). Naturally, the most desirable logs are knotless butt logs (Kataikko 1996, Kärki 1997, Kivistö et al. 1999), but all logs of average quality are also in demand. Slight crookedness is allowed by 60% and decay and knots by 40% of the sawmill entrepreneurs (Kataikko 1996). No requirements for diameter and length are set for masur birch, which is wanted as long spars (Kärki 1997).

At present each enterprise has its own requirements for birch logs and sawn timber. In addition, sorting regulations are being developed in Finland (Isomäki and Leppänen 1992, Leppänen 1992, Jouhtinen 1994, Keinänen and Tahvanainen 1995). Grading regulations have also been made in Sweden (Bestämmelser... 1943, Mätningsinstruktioner... 1987, see also Ekström 1987), in Norway (Kučera 1983, Kučera and Christiansen 1985, Fjaertoft and Bunkholt 1994) and in Germany (Steuer 1979). In these cases the regulations include also other deciduous trees. In Finland the pioneer in classification of birch logs and sawn timber by dimensions and quality has often been Vilkon Ltd. (Vilkonsaha kutsui... 1988, Koivutukin... 1988, Sahakoivun... 1988). The requirements of Vilkon Ltd. for saw logs and special logs for veneer cutting are presented in Appendix 1 and for unedged sawn timber in Appendix 2. Recently Vilkon Ltd. has made the requirements more specific by taking into account both the inner and outer flat surfaces and the moisture content (Sahakoivun... 1998).

4.2 Billets and Components

The idea of billets and components is to produce pieces of certain dimensions instead of traditional planks (e.g. Louna and Valkonen 1995, Kataikko 1996, Verkasalo 1997c, Pakkanen et al. 1998, Kivistö et al. 1999, Heräjärvi et al. 2000). The production of billets and components is increasing because it decreases the need for machinery and employees in furniture manufacturing. Enterprises have their own dimension and quality requirements for billets and components according to the products (Kataikko 1996, Kivistö et al. 1999). Sawing into billets thus emphasises the customer-related demands. The quality and moisture content of the billets are also adapted to the demands of the customer.

Birch is used as glulam boards, which should have sound knots and uniform colour, and as furniture legs and other small components in which slight differences in colour can be accepted (Harinen, pers. comm., Peltoranta, pers. comm.). Thus the quality requirements are high and they are also strictly controlled. Enterprises cannot afford weakened quality, because one of the main purposes of the billets is to minimise waste wood. As the consumption of birch wood in manufacturing furniture is 1.8 m^3/m^3 for sawn timber and 1.4 m^3/m^3 for billets (Kataikko 1996), the more expensive billets cannot be accepted if they are of low quality. The most significant problems with billets and components are the changes in moisture content at the time of delivery. Other defects caused by the raw material are dry knots, edge and dimensional defects, checks and also deformations and discolorations.

Attempts have also been made to develop regulations for classification of quality for furniture and their components. The regulations are made separately for painted, lacquered and abraded surfaces (Isomäki and Myllynen 1992). The factors included in determining the surface quality are, e.g. strength against mechanical and chemical stresses, cleanability and appearance. Thus only some of the requirements are directly related to the raw material.

5 The Properties of Birch Trunks and Wood and Their Improvement

5.1 Properties of Logs and Wood in Sawing and in Use

The general properties of birch determine its applicability for sawn timber and for furniture. The factors affecting the yield of birch products are mainly the same both in sawing and in rotary-cutting or slicing veneer (Lehonkoski 1937, Vaneritutkimuksia... 1937, Jalava 1938b, 1943, 1957, Enarvi 1939, Olavinen 1964, Heiskanen 1966, Meriluoto 1966, Kärkkäinen 1978a,b, Tuompo 1988a,b, Verkasalo 1997a,b). There are, however, a couple of significant differences between these industries in the relationship between product and raw material. The cut logs for sawing are longer than the veneer bolts, which makes it possible to remove a defective part from a veneer log but not from a saw log. However, the end-products made of sawn timber are usually quite short, which should be taken into account. Defects can be seen in larger a proportion of veneer sheets than of sawn timber pieces; but in veneer the defects are usually patched up. It is also possible to patch up defects in sawn timber pieces, although it is not common. Otherwise, when the yield decreases, defects in timber can only be ignored or avoided. On the other hand, false heartwood (e.g. Hallaksela and Niemistö 1998), which is very common in birch, remains in the veneer core; but in sawing it goes into the heartwood piece. Thus all the factors affecting the size and defects of logs are harmful in sawing. For example, 2.75 m^3 of log wood is needed, even 3.0 m^3 if small low quality logs are used in quarter sawing, and 2.1 m^3 of large good quality logs when sawn through for a cubic metre of edged and unedged sawn timber, respectively (Peltoranta, pers. comm.).

When the two Finnish species of birch are compared, *Betula pendula* has been observed to produce more wood than *B. pubescens* as it grows larger both when grown naturally (Lehonkoski 1937, 1949, Warjus 1946, Koivisto 1958a,b, 1959, Fries 1964, Braastad 1966, 1968, Mielikäinen 1980, 1985, Langhammer 1982) and when planted (Erken 1972, Raulo 1981) and its trunk also grows straighter than that of *B. pubescens* (Kujala 1946, Sarvas 1949, 1951, Heiskanen 1957, Verkasalo 1997b,c). As an exception, Mielikäinen (1985) observed that the crookedness of the butt log, the branchiness of the trunk and decay are more common in *B. pendula* than in *B. pubescens* but that the crookedness of the top and knottiness are more common in *B. pubescens*. Longitudinally fluffy and cross-sectionally light, hard, tight and glossy reaction wood, which makes tooling difficult, is very common in birch because of the crooks. In *B. pubescens* the proportion of reaction wood may be as high as 25–30% (Ollinmaa 1956). Thus the utilisation of birch wood in the mechanical forest industry is complicated by the relatively small size and crookedness of trunks and logs, branchiness and/or ovality, knottiness, frequent decay and discoloration (Heiskanen 1957, 1966, Heiskanen and Salmi 1976, Kellomäki and Salmi 1979, Kärkkäinen 1979, 1980, 1984, Salmi 1987a, Verkasalo 1990, 1997a,b,c, Heräjärvi et al. 2000). Average dimensions of birches used for saw and veneer logs are shown in Table 5.

Birches were divided into different groups based on the type of bark when much veneer birch was available (Warjus 1946). He claimed that the quality of wood can be determined on the basis of bark, wood of trees with thin grey bark being the best.

The combined effects of the defects in birch trunks are seen most evidently in the proportions of usable and unusable trunks and trunk parts, and especially in the rejected saw timber, i.e. the difference between the log volume determined on the basis of size, and size and quality requirements together. Defects causing rejection are most common in over-aged, unthinned birch stands. The amount of rejection depends on the growing site, the birch species, and the age

Table 5. Results on the average size of naturally regenerated log-quality birches in Finland. NFI – National Forest Inventory.

Research	Area	Birch species	Growing site	Number of observations	Average breast height diameter, cm
Heiskanen 1957	Eastern and southern Finland	*B. pendula*	MT-OMT	Hundreds	27.9
			Fertile peatlands	100–200	23.5
		B. pubescens	MT-OMT	Hundreds	23.7
			Fertile peatlands	Hundreds	19.8
Kohmo 1984	Southern, eastern and central Finland	*B. pendula*	All (7. NFI)	Thousands	28.5 [1)]
		B. pubescens	All (7. NFI)	Thousands	25.1 [1)]
Verkasalo 1990	District of Päijänne, central Finland	*B. pendula*	MT-OMT	67	24.7
		B. pubescens	Grassy peatland	51	23.7
			MT	43	22.2
Verkasalo 1997a,b	Central and northern Pohjanmaa	*B. pendula*	VT+-MT	112	24.5
			Grassy *Vaccinium myrtillus* and tall-sedge mires	32	22.8
		B. pubescens	VT+-MT	80	23.9
			Grassy *Vaccinium myrtillus* and tall-sedge mires	204	21.8
Luostarinen (unpublished)	Northern Carelia	*B. pendula*	VT-MT	80	29.9

1 Weighted by log volume

and size class (Heiskanen 1957, Koivisto 1966, 1968, Mielikäinen 1980, 1985, Verkasalo 1997b, Heräjärvi 2000). According to Salo (1954), the proportion of defective log-size birches is about 44% of the total volume of birch, which corresponds to a loss in value that may be as high as 20%. The rejected saw timber in the top part of the trunk is often due to too many branches (Heiskanen 1957), but also to crooks, vertical branches and decay (Verkasalo 1997b,c).

After the saw timber from the top is rejected due to poor quality, trunks can be classified into wholly usable trunks, trunks with rejected saw timber in the butt or in the middle of the trunk and totally rejected trunks (Heiskanen 1957). In southern and eastern Finland, for *B. pubescens* the proportion of wholly usable trunks was 52–65% and for *B. pendula* 59–76% depending on growing site (Heiskanen 1957), while in the district of Pohjanmaa Verkasalo (1997b) found 4–12% lower figures for *B. pubescens* and 12–30% higher figures for *B. pendula*. The number of totally rejected trunks was larger in Pohjanmaa (Verkasalo 1997b) than in southern and eastern Finland (Heiskanen 1957). Rejection of saw timber from the butt of the trunk was due to crooks, scars, decay, knots and surface checks depending on the growing site (Aro 1935, Salo 1954, 1955, Heiskanen 1957, Verkasalo 1997b). Also for rejection of saw timber from the middle of the trunks, the most common reasons are crooks, knots and scars (Heiskanen 1957). The number of rejected log-size trunks is exceptionally large if the birch stand has been cut selectively, especially on dryish heaths (55%) (Sarvas 1944). The reasons for total rejection are the same as for rejections of the butt and middle part of the trunk (Sarvas 1944, Heiskanen 1957, Verkasalo 1997b); but in some cases, most important of all is decay (Sarvas 1944).

The most serious factor decreasing the quality of birch wood are the dead branches below the living crown. This is because of their sensitivity to decay, which spreads readily through those branches into the trunk (Appelroth 1946, 1949). Birch trees are indeed very susceptible to decaying of the trunk (e.g. Sarvas 1944, Heiskanen 1957, Verkasalo 1997b). Factors that indicate decay in the trunk are old age, growing on thick peatland, damage caused by moles, checking of the trunk, scars and decayed knots (e.g. Heikinheimo 1917, Mikola 1942, Heiskanen 1957, Verkasalo 1997b). The fact that a tree originates from a sprout does not directly indicate decay: Ferm (1990) observed that decay had spread from stump to sprout in only 25% of all decayed sprouts (54% of sprout-origin birches). Nor does the research of Verkasalo (1997b) support the idea of a relationship between sprout-origin and susceptibility to decay.

Trunks of planted birches are often irregularly shaped. In particular, 30-year-old birches grown in a field have more bends at the base of the trunk, they are often more crooked and their tops are more often damaged than birches of the same age growing on mineral soil (Niemistö et al. 1998). Discolorations around the pith are also very common in planted *B. pendula* (Hallaksela and Niemistö 1998). The discoloured false heartwood is still hard in young, 18–30 year-old trees, its diameter is usually less than 4 cm and it reaches the height of 3–6 m. This is harmful in saw logs. The probable reasons for the discoloration are damage in the knots and bark. In addition, the amounts of bacteria and fungi are markedly increased in the discoloured wood compared to sound wood. Real decay-causing fungi are absent in this stage, although incipient decay was observed in 6% of sampled birches (Hallaksela and Niemistö 1998).

5.2 Characteristics of Wood

5.2.1 Structure

Birch wood is diffuse-porous and the proportion of summer wood is small. The density of summer wood does not differ markedly from that of spring wood, and the rays are barely visible to the naked eye. The homogeneity in the structure and appearance is an advantage for birch wood. The proportions of vessels, rays and fibres in the wood of *B. pendula* are about 18%, 7% and 75% by volume, respectively (Jensen 1950). In addition to these, the tissue includes some longitudinal parenchyma. Observations on *B. pubescens* show that its cross-section contains fewer vessels and rays per unit area than that of *B. pendula* (Bhat and Kärkkäinen 1980), but its fibres are longer, as much as 13% (Bruun and Slungaard 1959), and thicker than those of *B. pendula* (Kujala 1946, Bhat and Kärkkäinen 1980, 1981b, Mali 1980, Salmi 1987a,b, see Ollinmaa 1955). There is, however, no significant difference between the fibre lengths of spring and summer wood (Ollinmaa 1958). The xylem of *B. pendula* and *B. pubescens* can be separated anatomically according to the perforation plates of the vessels (Bhat and Kärkkäinen 1980), but this difference has no significance for the quality of wood for utilisation by the timber or furniture industry. The anatomy of birch wood has been described in detail by many authors (e.g. Wallden 1934, Jensen 1950, Bhat 1980b, 1983, Kučera 1980, Bhat and Kärkkäinen 1981a,b, Vadla et al. 1982, Wagenführ 1996).

The size and proportion of different types of cells vary in different parts of the trunk. The proportion of fibres decreases as the number of vessels and parenchyma increases from breast height to the crown (Bhat and Kärkkäinen 1981a). In a radial direction, the proportion of fibres increases from core to surface (Wallden 1934, Bhat and Kärkkäinen 1981a), which explains the corresponding increase in density (Bhat and Kärkkäinen 1981a). The length of the fibres (Wallden 1934, Bhat 1980b, Bhat and Kärkkäinen 1981b) and their diameter, the thickness of the cell wall (Bhat 1983) and the length of the vessel elements (Bhat and Kärkkäinen 1981b) increase from the core to the surface of the trunk, while the cells become shorter from the butt to the top of the trunk (Bhat and Kärkkäinen 1981b). The length of the fibres (Wallden 1934, Bhat 1980b, 1983), the thickness of the fibre wall, the percentual amounts of fibres and vessels (Bhat 1983) and the distance from the core (Bhat 1980b) correlate positively with the density of birch wood; but density correlates negatively with the height in the trunk and the thickness of the annual ring (Hakkila 1966, Bhat 1980b).

Average anatomical properties of birch wood are presented in Appendix 3.

Reaction wood, which is common in birches, is heavier than average normal wood, because it contains fewer vessels than normal wood, and the fibres are thinner and their walls (tertiary wall) are thicker than those of the normal wood, which means that their lumen is quite small (Ollinmaa 1956). The great length of reaction wood fibres is more likely connected to the different radial growth on different sides of a tree than to the reaction wood itself, because in *B. pubescens* the radial growth and the length of fibres correlate positively (Ollinmaa 1958). The lignin and extractive contents of reaction wood are, to some degree, lower but the cellulose content is markedly higher than in normal wood (Ollinmaa 1955, 1956).

Brown streaks may occur in the xylem at the butt end of the birch trunk. These streaks are very unfavourable, especially in veneer but also in sawn timber. The streaks are caused by the larvae of an insect, *Phytobia betulae*, which makes parenchymatic flecks in the xylem near the cambium (e.g. Kangas 1935, Salmi 1987a,b, Bhat 1980a,b, Ylioja et al. 1998). Bhat (1980a) observed that *B. pubescens* is more sensitive than *B. pendula* to *P. betulae.* In the study of Verkasalo (1997b) the difference between species was similar but very small.

5.2.2 Physical, Mechanical and Chemical Properties

In terms of utilisation, the woods of different European birch species are of equal quality (Sachsse 1988, 1989). The woods produced by the birch species that are economically important in Finland, *B. pendula* and *B. pubescens*, are not even separated at plywood or saw mills or in use. Exceptions are the masur, flamy-grained and ice birch woods, which are variations of *B. pendula* (Jensen 1953, Salmi 1987a). Masur wood is due to abnormally grown rays (Salmi 1987a, Fagerstedt et al. 1996), while in flamy-grained birch the direction of the fibres is wavy (Salmi 1987a, Fagerstedt et al. 1996), and in ice birch the direction of the fibres alternates irregularly, creating the reflective appearance of ice (Jensen 1953). Colour of birch wood is commonly very light, plainly coloured with a yellowish or reddish tone, but the wood of *B. pendula* may be slightly darker than that of *B. pubescens* (Salmi 1987a). *B. pendula* and *B. pubescens* do not produce heartwood (Farmer 1981, Kärkkäinen 1984, Kučera and Myhra 1996), although the core and the wood around the core usually turn dark (false heartwood), indicating the beginning of decay (Kučera and Myhra 1996).

The water content of a birch trunk is highest in the middle of the trunk (Nagoda 1969), except in the spring in the sapwood of the lower parts of the trunk (Peterson and Winqvist 1960). The moisture content of the tree base may be very low, especially in summer when the differences between the other, wetter parts of the trunk are small (Hakkila et al. 1970). Seasonal changes in the moisture content of birch timber may be as high as 40 unit percent (Hakkila 1962, Marjomaa 1992). The difference in the moisture contents of fresh sap and core wood is, however, quite small (Salmi 1987a,b).

Birch wood is of medium density. The juvenile wood near the core is the lightest and the wood at or near the surface is heaviest. *B. pubescens* wood is somewhat less dense than that of *B. pendula*, 480 kg/m^3 vs. 500 kg/m^3 (Runqvist and Thunell 1945, Kujala 1946, Ollinmaa 1960, Hakkila 1966, 1979, Velling 1979, Wagenführ 1996, Verkasalo 1998), but there is no difference in the wood density of rapidly and slowly growing trees within a species (Ollinmaa 1960). The medium wood density guarantees sufficient strength, elasticity, ductility and flexibility for carpentry and the furniture industry (Salmi 1987a,b). Owing to the relationship between density and strength, the lighter *B. pubescens* is, both in products of solid wood and in veneer, slightly weaker than *B. pendula* (Jalava 1945, Kujala 1946, Ollinmaa 1960, Mali 1980, see Ollinmaa 1955); but in practice this difference is masked by knots and angled grain. Birch wood swells and shrinks moderately as the ambient moisture content fluctuates. Physical characteristics of birch are discussed in detail by e.g. Kučera (1980) and Vadla et al. (1982).

The tensile strength of birch wood is quite low when compared to the density of the wood

(Jalava 1938a), which is partly why birch wood is not used as structural timber (Kärkkäinen 1984). Nor is birch wood very hard, but the hardness can be improved by pressure treatment with high temperature and humidity (e.g. Viitaniemi 1996), although heat treatment may reduce the modulus of rupture (Viitaniemi and Jämsä 1996). Fresh reaction wood, in particular, (Ollinmaa 1956, Kärkkäinen and Raivonen 1977) but also dried normal wood of birch is weak with regard to compression strength (Ollinmaa 1955). The bending strength is best and the fibres longest at a height of three metres in the trunk where the density is also highest (Wallden 1934). The strongest wood contains the fewest vessels (Wallden 1934). Mechanical characteristics of birch are discussed in detail by e.g. Vadla et al. (1982).

Dried birch wood is very durable in dry conditions; but outdoors, in alternating weather and moisture conditions, it is very sensitive to fungal and insect damage and it decays rapidly (e.g. Kučera and Myhra 1996, Wagenführ 1996). Thus it is not suitable for outdoor use (Farmer 1981, Wagenführ 1996, see Kučera and Myhra 1996), even though some good results have been achieved in impregnation tests of birch wood (Borup and Rennerfelt 1960, see Vadla et al. 1982, Kučera and Myhra 1996). However, impregnated birch wood is not in use.

Average physical, mechanical and chemical properties of birch wood are presented in Appendix 3.

5.3 Variation in Wood Properties by Growing Site and the Effects of Silviculture on These Properties

The growing site is of primary importance for the growth rate of birch and for the quality of birch logs (Appelroth 1949, Heiskanen 1957, Verkasalo 1997b,c). Unlike conifers, the strength of birch wood is improved by rapid growth (Jalava 1945). In birch trees grown on unfertile soils, the high lignin content of the xylem impairs the strength of the wood (Liepins 1933). In addition, rapid growth decreases the transverse and volumetric shrinkage but slightly increases the longitudinal shrinkage and the amount of juvenile wood (Dunham 1996). *B. pendula* grows on more fertile sites than *B. pubescens* does (Heiskanen 1957), which surely affects its superiority as sawn timber. In addition to the soil, light also affects birch growth (e.g. Messier and Puttonen 1995); and despite the amount of light, the xylem production in stem and branches differs markedly between different parts of the crown. This affects the tapering of the trunk (Denne et al. 1994).

Pure naturally grown birch stands are quite rare nowadays as there are few burn-beaten areas: birch commonly grows in mixed forests with conifers. In pure birch stands the dominant trees have the best shaped trunks, while in mixed forests with conifers the dominated birches may have the best trunks, at least in northern Finland (Tikka 1949). Appelroth (1949) claimed that the best birches grow in spruce forests if birch grows as an equal with spruce, while in Scots pine forests the dominated birches grow slowly because the availability of light is limited (Messier and Puttonen 1995).

Birches growing on mineral soils produce wood and timber of better quality than those growing on peatlands, which may be partly due to the fact that more *B. pubescens* than *B. pendula* grow on peatlands (Heiskanen 1957). In spite of this, the best peatlands, e.g. spruce mires, can grow birches of good quality (Lukkala 1931, Lappi-Seppälä 1933, Verkasalo 1997b). When peatlands are reforested, *B. pubescens* is an acceptable alternative, even though it is not favoured on mineral soils (Saramäki 1977, 1981, 1994, see Kärkkäinen 1984). However, according to Verkasalo (1997b,c), *B. pubescens* growing on mineral soils is more valuable than it is usually believed to be. Birches planted on a field are often thicker than birches grown on mineral soils, but no differences in length were observed (Niemistö 1998b). Also, the branches are thicker in birches growing on a field than in those on mineral soil, and the thick branches are pruned slowly. Defects in trunk form are, however, more common in birches growing on a field. Birches, especially *B. pubescens*, grown on the rare remaining burn-beaten areas very often have decayed from inside the trunk (Heikinheimo 1915).

Young birches should grow in dense stands so that the trees grow straight and the lower branches die and drop (Appelroth 1949, Niemistö 1995a). If the branches do not drop naturally, pruning is a good way to improve the quality of saw or veneer log wood in order to produce sound and knotless sapwood both in planted and in natural forests. The problem with pruning is that it easily causes decay. Therefore it should be done carefully without affecting the tree itself and only for dead branches (Appelroth 1949, Raulo 1981), or for living branches smaller than 15 mm in diameter (Rintala 1995, Verkasalo and Rintala 1998). Selective cutting may also seriously damage the remaining birches. This shows up later as decay (Sarvas 1944, Salo 1954). As a growing tree, birch is indeed very sensitive to decay, and defects may significantly lower the quality and value of the trees (Ohman 1970, see Kärkkäinen 1984). To guarantee good growth rate and branch dropping, thinning should be done when growth has started properly and proceeded a while (Appelroth 1949, Niemistö 1995a). If thinning is too extensive, the branches will grow thicker (Cameron et al. 1995, Dunham 1996) and the tapering of the trunk increases (Cameron et al. 1995). In addition, the increase in light caused by thinning may emphasise the growth of epicormic branches on the trunk (Zobel and van Buijtenen 1989); such branches have also been observed to occur on Finnish birches (Heiskanen 1957, Verkasalo 1997b). Too large a growing space increases the butt swelling, shortens the branchless trunk and decreases the total length of at least *B. pendula* (Dunham 1996). Thus, density of the stand affects the diameter growth of the trees (Cameron et al. 1995, Niemistö 1995b), but does not have much effect on the quality of the wood (Cameron et al. 1995, Dunham 1996). In some hardwoods it has also been observed that the size of growing space affects the amount of growth stresses in the wood (Saurat and Gueneau 1976, Waugh 1977, Polge 1981, Ferrand 1982).

On both mineral soils and peatlands, the growth rate of birches can be improved to some extent by forest improvement measures. Ditching of peatlands has been shown to increase the growth of birch and simultaneously strengthen the wood (Ollinmaa 1960). Fertilising may slightly reduce the density of the wood while also increasing the growth rate (Saikku 1975). Nitrogen fertilisation during the next summer after planting may cause a short-term increase in height growth by as much as 80% (Viro 1974), and different types of nitrogen fertilisers have the same effect (Paavilainen and Norlamo 1975). For well-growing seedlings fertilisation is unnecessary in the viewpoint of growth (Oikarinen and Pyykkönen 1981, Raulo 1981, Moilanen 1985), but it may be reasonable to fertilise trees that are almost log-size (Raulo 1981).

5.4 Breeding and Renewal of Forests with Birch

The breeding of birches in Finland has concentrated on the more important of the two Finnish birch species, *B. pendula,* while *B. pubescens* has not been bred as extensively (Lepistö 1970, Viherä-Aarnio 1989, 1990). Breeding work in Finland has been going on for some decades. The growth rate of the trunk (Raulo and Koski 1977, Raulo 1979, 1981, Lepistö 1981, Hagqvist 1986, 1998), the form of the trunk and the branchiness (Raulo 1979, 1981) can be improved by breeding, but a factor that complicates the work is that good growth rate, good external quality and high wood density seldom occur together (Velling 1979). In addition, a harmful positive correlation has been observed between wood density and shrinkage, while growth rate and density do not affect each other (Nepveu and Velling 1983). On the other hand, cloned *B. pendula* plantlets have proved to be quite different in growth, whereas tissue-cultured plantlets of the same origin and seedlings of the same origin have grown quite similarly (Minkkinen 1992). Selection of fast-growing and well-producing birch progenies is thus considered to be the best method for establishing economically profitable birch stands (Wang and Tigerstedt 1996, Hagqvist 1998).

Gene manipulation is also under investigation in birches, but the research is still fairly new and has not yet produced any commercial strains. A gene that has been transferred into birch (*B. pendula*) is the chitinase gene (Keinonen-Mettälä and von Weissenberg 1999), which is supposed to improve the resistance to fungi by breaking down the chitin in the cell walls of fungi (Tuominen, pers comm.). Transfer of genes that identify the 'stress hormone' ethylene is also under investigations. The role of ethylene in e.g. ozone and pathogen stress as well as in cold tolerance are investigated in this way, and such studies may lead to the improvement of stress tolerance if the genes involved in the process can be recognised (Tuominen, pers. comm.). This might improve the quality of wood, e.g. by decreasing the discolorations and decay caused by fungi and bacteria spreading through frost cracks. The lignin synthesis of *B. pendula* is also under genetic investigation. The synthesis is investigated by transferring genes that affect lignin synthesis, e.g. the *O*-methyltransferase gene, to micropropagated birches. The purpose is to ascertain how this gene affects the properties of wood (Häggman 1998).

A birch stand can easily be renewed because birch produces many seeds and the growth of seedlings is rapid especially if the ground is broken, e.g. by plowing, and fertilised. A certain progeny can thus be cultivated by sowing although the competition from the undergrowth may be harmful (Raulo and Lähde 1976, 1981). Planting of seedlings on a reforested site is, however, the most common (Mikkola 1997) and the most reliable (Saksa 1998) method, but the risk of trees developing butt crooks or sweep is higher with planted seedlings than with sowed seedlings (Kurkela 1977). The right technique in planting is also important because roots placed unsymmetrically may cause the tree to grow askew and thus produce much reaction wood – such trees are also susceptible to wind and snow damage (Zobel and van Buijtenen 1989). Many crooked trunks and bends at the bases of the trunks of planted birches due to the leaning of the tree have been observed (Niemistö 1998b). The mortality of small seedlings is the highest; thus planted birch seedlings should be as large as possible (Raulo et al. 1998). See the summary of birch cultivation written by Raulo (1978).

Both in sowed and planted stands, weed control is important even with large seedlings (Leikola 1976), especially on fertile sites (Niemistö 1995b). It has been observed that the use of herbicides increases the growth of *B. pendula* seedlings significantly, while cover plants and chips increase the damage caused by moles (Ferm et al. 1994). In general, damage by animals, both insects and mammals, has proved to be a serious problem in planted *B. pendula* stands (Juutinen et al. 1976, Raulo and Lähde 1977, Lähde and Raulo 1977, Annila 1979). These stands are believed to be extremely sensitive to *Phytobia betulae* because the planted stands are spacious compared to natural stands, which makes the conditions favourable for the fly (Schulman 1989, Ylioja et al. 1998). Fast-growing birches have been found to be more susceptible to *Phytobia* attack than slow-growing ones (Ylioja et al. 1995, Niemistö 1998a). Fortunately, the damage is apparently mostly located near the core (Niemistö 1994, 1998a).

Renewal of a birch stand by coppicing is a questionable alternative if the aim is to produce trunk wood of good quality (Tikka 1949, Ollinmaa 1955, 1956, Verkasalo 1997b) and free from decay (Mikola 1942, Tikka 1949, see Ferm 1990, Verkasalo 1997b). This is due to the fact that birch sprouts from the basal buds are located in the stump (e.g. Kauppi 1989) and thus the sprouts start to grow crooked as they try to grow upright although they must also give space to other sprouts in the same stump. Coppicing may be a good alternative when birch is cultivated for pulpwood (Kärkkäinen 1984, Ferm 1989, 1990) because the growth rate of the sprouts is extremely good in the beginning (Kauppi 1989), even though in a few years the rate declines to the same level as that of seedlings (Paukkonen and Kauppi 1998). In addition, coppicing increases the sprouting potential because it causes the basal buds to branch vigorously (Kauppi 1989).

6 Birch Timber from Forest to Product

6.1 Felling, Transport and Storage

Birch was the last Finnish tree species for which mechanised felling was started. At the time it was doubted that machine logging would cause detrimental peeling of birch logs, defects in the wood when trimming, and end splits during felling or cutting into lengths. These defects decrease the yield of veneer or sawn timber and thus also the quality (Mäkelä 1993). Peeling and end splits as well as inaccuracy in cut lengths do indeed occur when logged by machine in early summer, but in other months the differences between logs cut by machine or by man in terms of the numbers of the defects referred to above were quite small (Mäkelä 1993, 1994). The inaccuracy in lengths is due to the peeling of the bark because this peeling makes feeding of the trunks difficult (Mäkelä 1994). The most important factors affecting splitting in mechanised felling are the working techniques, experience and training of the driver (Mäkelä 1993). On the other hand, trimming defects are always more common in machine-cut logs, especially with machines that have feeding reels made of steel, than in man-made logs (Mäkelä 1993, 1994).

Felling in the winter is recommended for birch because icy trunks are not damaged during storage. In an experiment, birch logs felled in winter were buried in the snow and then covered with sawdust. This method kept the temperature of the storage lower than +2.5 °C during the summer, and in the autumn the logs seemed to be in a condition corresponding to freshly felled trunks (Metsäliitto hankkii... 1997). During warm seasons birch logs do not tolerate long storage because discolorations, checks, decay, and insect damages develop rapidly in the forest and in industrial storage (Jalava 1938b, Henningson 1964, 1970, Salmi 1964, Hakkila et al. 1970, Pekkala and Uusvaara 1980, Aantio 1987, Verkasalo 1993). If storage lasts only one summer, however, logs do not usually get serious decay or insect damage (Jalava 1938a, Heiskanen 1958, 1959, Hakkila 1963, Henningson 1964, 1970, Salmi 1964, Hakkila et al. 1970, Pekkala and Uusvaara 1980, Aantio 1987, Verkasalo 1993). This depends, however, on the conditions of the particular summer because weather and insect conditions vary greatly from year to year (e.g. Kangas 1935). Logs with bark do not dry during storage so much that their susceptibility to decay would decrease (Heiskanen 1958, 1959), but drying checks that reach the core (heart checks) may develop rapidly (Aro 1960). For example, Salmi (1964), Pekkala and Uusvaara (1980) and Verkasalo (1993) observed that storing decreases the density and moisture content of birch wood; but according to Verkasalo (1993), this decrease is less in *B. pubescens* than in *B. pendula*. Discolorations are common, especially in birch wood imported from Russia; the reasons for this are probably the high age of the trees and the long storage time (Verkasalo 1997c). Birch logs stored in water remain without discolorations while “air storing” causes discolorations (Heiskanen 1958, 1959). Storing in water causes other defects, however, e.g. waterlogging as a result of increased permeability (Esping 1996), and is not used for birch saw logs.

Birch trunks are usually cut into logs and trimmed immediately after felling; but earlier, leaf-felling was important especially for veneer birches (e.g. Jalava 1938b, Hakkila 1963, Hakkila et al. 1970). In leaf-felling the branches and leaves are left on the tree providing a large surface for evaporation of the water from the wood (e.g. Jalava 1938b). In this way a birch trunk may in 3–4 days lose 40–50% of the water it contains when fresh (Jalava 1938b, Hakkila 1963). Birch trunks leaf-felled in July and August do not discolour during the felling summer, but discoloration starts to develop immediately at the beginning of the next summer (Jalava 1938b).

When manufacturing of plywood increased, birch logs had to be purchased quite far from the factories, and therefore birch log floating started and was carried out as the softwood logs had been floated earlier. The reason for floating was its cheapness, ease and also the fact that it may have been the only way to transport the logs (Jalava 1938b). To float, birches must be leaf-felled, because the heavy, water-laden logs sink easily (Jalava 1938b, Hakkila et al. 1970). To prevent the storage defects, floating should be done either during the felling summer or at the beginning of the next one, depending on the date of felling (Jalava 1938b, Hakkila et al. 1970). Nowadays, when trees are felled by machine, they are transported mainly by truck but also by train. The damage occurring during transport is thus minimal.

6.2 Sawing and Drying

The method of sawing is important in determining the quality of hardwood sawn timber. Factors that should be taken into account in choosing the sawing method are shrinking and checking during drying, deformations and the dimensions of the sawn timber (Saimovaara 1994). The following course of sawing is recommended (Hoadley 1980): first the surface of the log is sawn away to determine the internal quality, then the log is sawed into blocks, juvenile wood is removed, blocks are allowed to dry for a couple of months to a couple of years to remove the growth stresses, blocks are quarter-sawn and finally the boards are dried slowly (2–3 years). In practise this is not possible at the Finnish sawmills because it is too expensive a method. Sawmills must be able to send the wood to the industry as rapidly as possible.

Quarter-sawn wood makes the board surfaces uniform, because the texture of the annual rings is constant. It also decreases the disadvantages of shrinking and swelling because the different tangential and radial deformations can be directed in their own directions. In spite of this, almost all wood in the mechanical wood industry is sawn through, usually in the direction of the pith, and after that the timber is dried artificially. This method makes good use of, in particular, sapwood of good quality (Kataikko 1996). Sawing through in the direction of surface might be even more profitable with logs with a strong taper resulting in straight grains; deformations may decrease and the sapwood can be used as efficiently as possible (Paukkonen et al. 1999). The double cut method is also used with birch. Its advantages in birch sawing are the speed of the sawing process and the possibilities to automate sawing compared to e.g. through-sawing. Thus double cutting is used mainly for small logs and thick defective logs, when no marked increase in value of the timber can be achieved by "quality sawing". Because bark slows drying, the birch logs are sometimes debarked before sawing (Verkasalo 1997c). Sawing methods for hardwoods are discussed in detail e.g. by Hoadley (1980) and by Keinänen and Tahvanainen (1995).

While steaming (Salmi 1987a,b) and artificial drying change the colour of birch wood to yellowish, reddish or brownish, even spotty, especially inside the boards, birch wood has been shown to retain its light colour when boards are allowed to dry in room conditions (Paukkonen et al. 1999). Discolouring of the inner parts of pieces of sawn timber means that a light layer of some millimetres thick occurs at the board surface, causing stripes in glued birch products. Preliminary examinations of birch wood discoloration suggest that phenolic proanthocyanidins may be involved in the colour reactions during kiln drying (Paukkonen et al. 1999, Paukkonen and Luostarinen 1999, Luostarinen and Luostarinen 2000). The extractives, e.g. phenolic substances, are located mainly in the rays and in the longitudinal parenchyma (Perilä 1954, Perilä and Toivonen 1958, Paasonen 1967). Fungi and bacteria may also be involved, as they have been found in both discoloured and light birch wood (Hallaksela and Niemistö 1998); and in other hardwoods it has been shown that the change in pH caused by bacteria and fungi may change the colour of certain phenols in the wood (Zimmermann 1974, Starck et al. 1984, Bauch et al. 1985, Yazaki et al. 1985).

Drying, especially drying of thick birch planks is difficult with the conventional kiln process (e.g. Johansson 1996, Harinen, pers. comm.). Even a drying schedule that has usually worked well may sometimes produce discoloured wood (Harinen, pers. comm.). Birch boards have been successfully dried without discolorations if the temperature at the beginning of the drying process has been ca. 30 °C and then raised gradually to

70 °C (Harinen, pers. comm.). The drying temperatures that have been tested for birch planks are about the same, but the temperature at the beginning of the drying process has been set at 50 °C; this study does not refer to the wood colour at all (Jørgensen et al. 1995). Vacuum drying, in which water boils at low temperatures (air pressure 100–200 mbar, corresponding to a water boiling point of 45–60 °C) and it is possible to dry wood in few days, have proved to be good for drying birch as the colour remains evenly light (Varis 1997, Lahtinen, pers. comm.).

Stacks cause discoloured spots in birch wood during drying (sticker staining). Stacks made of plastic do not cause spots, but they are too expensive to use; grooved aspen stacks have also proved to be a good alternative (Peltoranta, pers. comm.). To minimise sticker staining, stacks should be as dry as possible (Smith and Herdman 1996), and stacks made of different tree species may affect the development of staining differently (Peltoranta, pers. comm.).

A user of birch sawn timber claims that to avoid discoloration birch needs to be stored between sawing and final drying (Kataikko 1996); but if storage is timed to very warm weather, this may also cause discoloration (pers. obs.). For example, a user of a birch sawn timber wants birch to be sawn by the end of March and then allowed to dry a couple of months outside before final drying (Peltoranta, pers. comm.). Drying that occurs during the transit storage of both logs and sawn timber also decreases the drying costs.

During drying, the reaction wood of birch often remains lighter than the normal wood (Ollinmaa 1956), which may be due to the smaller extractive content of reaction wood (Ollinmaa 1955). This increases the spotted appearance of birch wood. Reaction wood also checks readily, and strains that cause warping, twisting and checking cannot be avoided (e.g. Ollinmaa 1956, Kärkkäinen 1984). A sufficiently long conditioning and the subsequent cooling are also necessary for normal wood in order to minimise strains, moisture gradient and checking in dry timber (Tronstad 1993, Jørgensen et al. 1995). In a sawing experiment strains have indeed proved to be the most serious problem depending on the birch wood itself, while checking and deformations were connected with drying conditions and could be minimised by sorting the sawn timber by length before drying (Fjaertoft and Bunkholt 1994). Sorting of sawn timber on the basis of the orientation of annual rings may also be useful because Paukkonen et al. (1999) observed that birch boards of different annual ring orientation deformed differently in different drying conditions. On the other hand, drying without weights on the load has not induced marked deformations to the upper boards of the load (Peltoranta, pers. comm.).

Heart checks may develop in birch timber during drying or steaming (Aro 1960, Juvonen and Kariniemi 1984, Kärkkäinen 1984), but most checking that is due to drying is limited to those birch boards which contain the core (Jørgensen et al. 1995). However, checking is not a serious problem in birch drying, as even the largest end checks, which are most common in boards sawn from large butt logs, can easily be ignored in use without significant amount of waste wood (Peltoranta, pers. comm.). The checking that occurs during drying has been studied theoretically also with birch by Siimes (1967).

6.3 Woodworking and Finishing

Tooling manually and machining are both easy with birch wood, in particular turning but also sawing, planing, veneering and carving (Salmi 1987a,b, Wagenführ 1996, see also Vadla et al. 1982, Kučera and Myhra 1996). On the other hand, ripping is quite difficult, as is any tooling of reaction wood. Drying may cause case-hardening and thus stresses in the wood. These stresses are freed after ripping or planing of one surface and cause board deformation, which makes machining more difficult and increases the amount of waste wood (e.g. Kollman and Côté 1984). Irregular fibre directions and knots also make difficulties in tooling, especially in planing and in bending (Kučera and Myhra 1996), but without them bending, in particular, is easy (Farmer 1981, Kučera and Myhra 1996). The differences in density affect the power needed in turning and sawing, which means that lighter *B. pubescens* is slightly easier to tool than *B. pendula* (Meriluoto 1966). This may be the reason for the opinion that *B. pubescens* veneers and sawn surfaces are more beautiful and smoother than those of *B. pendula* (Appelroth 1946). The planed surfaces of birch wood are commonly smooth and shine beautifully (Salmi 1987a). The shining makes wide surfaces look stripy if the grains in adjacent battens are not parallel.

When the forces needed for machining of several tree species were compared, birch machining required average force (Kivimaa 1952c, Kollman and Côté 1984). Cutting force is related to the density of the wood as well as e.g. to the thickness of the chip, blade angles, material and size of the blade, cutting depth, direction of cutting, wood temperature and moisture content (e.g. Kivimaa 1952a–d, Kollman and Côté 1984). The cutting force needed for birch wood is greatest when the moisture content is about 11%. Cross-cutting requires the most force, 9 kp/cm (chip thickness 0.1 mm), ripping longitudinally requires 3.5 kp/cm and ripping radially and tangentially 2 kp/cm (Kivimaa 1952 a–d).

The most important of the blade angles is the hook angle. When birch is cross-cut, the optimal angle is 45–53°, and for ripping it is about 60°. To achieve the minimum cutting force these hook angles need lip angles of about 30° and 20°, respectively; the optimal clearance angle is 10° (Kivimaa 1952c). When planing, the hook angle should be about 10°, because with larger angles the fibres of birch wood tend to rise (Kivimaa 1952d). However, machining with this small hook angle requires considerable force (Kivimaa 1952d). The velocity for cutting birch should be 28–33 m/s (Wagenführ 1996), although the velocity does not affect the cutting force (Kivimaa 1952d).

Joints of screws, nails and glue hold well (Farmer 1981, Vadla et al. 1982, Salmi 1987a,b, Redner and Rognerud 1991), although predrilling for screws is recommended (Farmer 1981, Vadla et al. 1982). Blueing caused by metal corrosion may occur (e.g. Salmi 1987a,b, Redner and Rognerud 1991). Finishing (lacquering, staining) gives good results (Salmi 1987a,b, Kučera and Myhra 1996); and as a light-coloured wood, birch is easy to stain to resemble many other, e.g. tropical timbers (Redner and Rognerud 1991, Kučera and Myhra 1996). Polyester lacquering may, however, cause defects in finishing (Wagenführ 1996).

7 Research Related to Birch Wood and Utilisation in Finland and Their Needs

7.1 Current Research

Many research and development projects on birch have been started by research institutes and universities, and as regional and local projects. This is motivated by the fact that there are good possibilities to increase the sawing and related further processing of birch in Finland, especially in many rural areas. In addition, the future of Finnish birch as a plywood raw material is not necessarily guaranteed and there is not enough demand for domestic small-sized birch timber, which means that new applications are being sought.

Great attention is now paid into the availability and properties of birch wood and their improvement, as the processing methods and logistics of birch from forest to end-product have not been developed as much as the quality needs set to birch timber and end-products would require. This includes the environmental factors (growing site, climate, silviculture, etc.) and their effects on wood properties. Factors associated with timber procurement, e.g. felling date, storage, bucking and sorting, are also included. In these and in sawing studies, an important standpoint is that of end-use. As the availability of birch timber is getting more difficult, both in quantity and quality, methods of economic and profitable sawing of small-dimensioned logs, both in length and diameter, have been developed. Factors of timber trade and profitability of forest management for the owners is also an issue for discussions and research.

A property that has become important in the context of joinery and furniture industries, e.g. parquetry, is the colour of birch wood: uniformly light-coloured wood is wanted in order to maximise the price or even to make sure that dried birch wood can be sold to factories. Thus, colour controlling in drying process and the chemical background of discoloration are under investigations, regarding both conventional and vacuum drying processes. Drying as a whole needs a lot of research for practical applications.

Research has only recently been focused on planted birch as the oldest planted stands have reached the log size. It is not sure that they are similar to natural birches in procurement and processing, depending on their new growing sites, sometimes abnormal for birch. Thus, discoloration and deformations of wood of planted birches during drying are studied, as well as factors that affect the wood quality in living trees, e.g. decay and discoloration caused by microbes of green wood. In this context, the growing site and spacing and their influences on aesthetic properties of wood, e.g. knottiness and other internal defects, are under investigations.

In addition, research in the field of gene technology includes research that may affect or improve the properties of birch wood.

7.2 Research Needs

There is a need to develop the procurement of birch timber, both from final fellings and thinnings, and consequently the whole chain from forest to end-use. The problems have been defined, but there has been no intensive search for solutions. The problems are not due to the lack of log-size birch trees, but rather to the fact that the resources are scattered in conifer and mixed forests or on special growing sites, which may be valuable conservation sites.

Demand of high-quality birch as roundwood or sawn goods for different needs of further processing has not ever been nor will be a problem for forest owners growing birch. Actual deficiency for both *B. pendula* and *B. pubescens* is the small proportion of good-quality, large-size logs of the total production during the whole rotation period compared with Scots pine and Norway spruce at similar growing sites. Accordingly, the main concerns continue to be, on one hand, in respecting and improving the quality of birch timber stock in all phases of silviculture and wood procurement, and, on the other hand, innovating and developing profitable uses for medium- and low-quality birch.

The large proportion of weak-quality log-size birches also causes problems. Consequently, because of their small amount in individual stands, even good quality butt logs are not properly sorted when these sites are being cut. Thus the sorting done in the forest should first be developed at final fellings and thinnings, but it might help to increase the cultivation of normal and masur birch in abandoned fields.

Even quite small birch logs, i.e. 2–3 m in length and less than 18 cm, maybe down to 10 cm in diameter, could be sorted profitably for sawing, as not only speed and productivity but also good quality are important factors in birch sawing. One estimate claims that, based on the form of the trunk and soundness of the wood, as much as 20–25% of the domestic birch roundwood going to pulp mills could be used as sawn wood (Kuusisto, pers. comm.). A recent investigation suggested an average yield of 12% for saw logs with the minimum diameter of 11 cm and length of 2.2 or 3.3 m from the total birch timber volume from thinnings, ranging from 3 to 18% by stand (Heräjärvi et al. 2000, Rantanen et al. 2000). For that, however, an automatic sawing equipment, with the line speed of 50–70 m/min at its minimum, would be necessary to improve the productivity of the process and the yield and quality of sawn goods from small logs, 7–25 cm in diameter.

Billet and component manufacturing should also be developed to optimise the use of wood. Their benefits are the good efficiency of the raw material, the sorting of timber according to its quality for the best end-uses, the decrease in the need of furniture and joinery industries to invest in primary processing, and the stabilisation of price changes in raw material and bulk products. To optimise billet and component making, sorting, settings in sawing and bucking by grade, the physical and chemical properties, their alteration and dependence on the growing site and location of wood in the radial and longitudinal directions of birch wood should be determined.

If no other way is found, it may be possible in the future to produce birches with a certain property by gene technology. For example, if selecting trees that do not discolour during drying is not enough, it may be possible to create this property by gene manipulation. However, this requires the knowledge of chemical and genetic factors affecting the specific property.

In the development of the furniture and joinery industries and in this way in raising the processing grade of the forest industry, the design, marketing, technical development of saw technology and increasing of wood use are all in key position. In addition, the raw material supply for the industries should be guaranteed, both in quality and quantity. Since the domestic markets for furniture and joinery products are limited, export should be increased. In order to increase interest in the Finnish products in the potential export countries, the industries should embark on the diversification and uniqueness of the production. High quality and industrial design are the keypoints.

In conclusion, a summary is presented of the research needs that appeared directly or were concluded from the data collected, to increase and intensify the utilisation of birch. These needs can be looked at from the standpoints of forest management, timber sales, wood procurement, wood industries, trade of wood products and end-uses. We emphasise the following issues:

1) possibilities to increase cuttings of domestic birch timber (thinnings, plantations and mixed stands with birch, among others),
2) expected timber recovery for different assortments and income from timber sales when harvesting different types of birch stands,
3) quality requirements for different assortments of birch roundwood, bucking stems, sorting roundwood timbers and channelling timber flow to different uses,
4) utilisation and improvement of the natural properties and genetic features of birch,
5) solving the practical problems related to sawing birch (yield and grade of sawn timber, sawing patterns, technical solutions, production economy),
6) solving the practical problems related to further processing of birch (discoloration and deformations during drying, billet and component manufacturing),
7) potentials for and restrictions of utilising birch wood, timber and products, and
8) market expectations and success factors of birch products.

Closing Words

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References

Aantio, M. 1987. Koivutukin varastoinnin taloudellinen merkitys vanerin valmistuksessa. Diploma thesis. Helsinki University of Technology, Wood Technology. 62 p. Otaniemi, Finland. (In Finnish)

Annila, E. 1979. Lehtikärsäkkäiden (Phyllobius, Coleoptera: Curculioinidae) aiheuttamat tuhot pelloille istutetuissa koivuntaimistoissa. Summary: Damage by Phyllobius weevils (Coleoptera: Curculioinidae) in birch plantations. Communicationes Instituti Forestalis Fenniae 97(3). 20 p.

Appelroth, E. 1946. Om björken och dess skötsel i Finland intill senaste världskrig. Norrlands Skogvårdsförbundets Tidskrift: 331–336. (In Swedish)

— 1949. Koivun kasvattamisesta. Metsätaloudellinen Aikakauslehti 66(12): 14–15. (In Finnish)

— , Eklund, H. & Forsbacka, M. 1971. Rapport över undersökning av glasbjörkens (Betula pubescens) förekomst och skogliga betydelse inom Vasa distriktskognämnds verksamhetsområde. Mimeograph. 152 p. + app. (In Swedish)

Aro, P. 1935. Tutkimuksia rinnankorkeus- ja katkaisuläpimitan vaikutuksesta käyttöpuun ja hakkuutähteiden määrään. Referat: Untersuchungen über den Einfluss des Brusthöhen- und Minimaldurchmessers auf die Menge des Gebrauchsholzes und der Hiebreste. Communicationes Instituti Forestalis Fenniae 20(4). 159 p. (In Finnish with German summary)

— 1960. Koivuvaneritukkien ja sorvipölkkyjen halkeaminen. Referat: Die Rissbildung in Furnierblöcken und Furnierabschnitten. Communicationes Instituti Forestalis Fenniae 52(4). 41 p. (In Finnish with German summary)

Bauch, J., Schmidt, O., Yazaki, Y. & Starck, M. 1985. Significance of bacteria in the discolouration of Ilomba wood (Pycnanthus angolensis Exell). Holzforschung 39: 249–252.

Bestämmelser om normalpriser å sågade trävaror av björk. Prisregleringens omfattning, kvalitetsbestämmelser, prisbestämmelser, mätningsbestämmelser och ansvarsbestämmelser. Stockholm, den 22 december 1943. Statens Priskontrollnämnd, Meddelande 395. Mimeograph. 4 p. (In Swedish)

Bhat, K.M. 1980a. Pith flecks and ray abnormalities in birch wood. Silva Fennica 14: 277–285.

— 1980b. Variation in structure and selected properties of Finnish birch woods. I. Interrelationships of some structural features, basic density and shrinkage. Silva Fennica 14: 384–396.

— 1983. A review of wood anatomy and selected properties of stems, branches and roots of birch species. IAWA Bulletin 4: 70.

— & Kärkkäinen, M. 1980. Distinguishing between Betula pendula Roth. and B. pubescens Ehrh. on the basis of wood anatomy. Silva Fennica 14: 294–304.

— & Kärkkäinen, M. 1981a. Variation in structure and selected properties of Finnish birch woods. III. Proportion of wood elements in stems and Branches in Betula pendula Roth. Silva Fennica 15: 1–9.

— & Kärkkäinen, M. 1981b. Variation in structure and selected properties of Finnish birch woods. IV. Fibre and vessel length in branches, stems, and roots. Silva Fennica 15: 10–17.

Björken blir glassticka. 1989. Skogsbruket 6: 24–25. (In Swedish)

Borup, L. & Rennerfelt, E. 1960. Undersökningar över möjligheten att impregnera björkvirke. Norrlands Skogvårdsförbundets Tidskrift: 97–120. (In Swedish)

Braastad, H. 1966. Volumproduksjon av gran og bjørk i Salten. Norsk Skogbruk 12 (23/24): 839–842. (In Norwegian)

— 1968. Volumproduksjon av gran og bjørk i Trøms. Norsk Skogbruk 14(4): 119–121. (In Norwegian)

Bruun, H. H. & Slungaard, S. 1959. Investigation of porous wood as pulp raw material. 3. Fibre dimensions of several NW European wood species. Paperi ja Puu 2: 31–34.

Cameron, A.D., Dunham, R.A. & Petty, J.A. 1995. The effects of heavy thinning on stem quality and timber properties of silver birch (Betula pendula Roth). Forestry 68: 275–285.

Denne, M.P., Atkinson, C.J. & Dodd, R.S. 1994. Quantification of trends in wood production within trees of silver birch (Betula pendula Roth). Annals of Botany 73: 655–664.

Dunham, R.A. 1996. The influence of growth rate on the wood and stem properties of silver birch (Betula pendula Roth.). PhD thesis, University of Aberdeen, Scotland.

Ekström, H. 1987. Lövvirke – tillgångar och industriell användning. Summary: Hardwood – supplies and industrial utilization. The Swedish University of Agricultural Sciences, Department of Forest Products, Report 197. 123 p. + app.

Elowsson, T. 1989. Förutsättningar för tillverkning av björkkomponenter – en tillverkningsgren med goda framtidsutsikter. Summary: Conditions for manufacturing of semiprocessed birch wood – a branch of production with a bright future. The Swedish University of Agricultural Sciences, Department of Forest Products, Report 206. 69 p. + app.

Enarvi, R. 1939. Vaneritehtaan sorvaushäviöiden suuruus. Suomen Puu 14(21): 396–399. (In Finnish)

Erickson, R., Petersen, H.D., Larson, T.D. & Maeglin, R.L. 1986. Producing studs from paper birch by saw-dry-rip. USDA Forest Service, Forest Products Laboratory, Research Paper FPL-465. Madison, Wisconsin. 13 p.

Erken, T. 1972. Planterad björk i mellersta och övre Norrland. Sveriges Skogsvårdsförbunds Tidskrift 70: 435–465. (In Swedish)

Esping, B. 1996. Trätorkning. 1b. Praktisk torkning. Trätek. 959 p. (In Swedish)

Fagerstedt, K., Pellinen, K. Saranpää, P. & Timonen, T. 1996. Mikä puu – mistä puusta. Yliopistopaino, Helsinki. 180 p. (In Finnish)

Farmer, R. H. 1981. Handbook of hardwoods. Princes Risborough Laboratory, London. 2nd ed. 243 p.

Ferm, A. 1989. Hieskoivun kasvatus soilla. In: Metsäntutkimuspäivä Kannuksessa 1988. Metsäntutkimuslaitoksen tiedonantoja 322. p. 40–51. (In Finnish)

— 1990. Nuorten vesasyntyisten hieskoivikoiden lahoisuus turvemailla. Summary: Development and decay of young Betula pubescens coppice stands on peatland. Folia Forestalia 744. 17 p.

— , Hytönen, J., Lilja, S. & Jylhä, P. 1994. Effects of weed control on the early growth of Betula pendula seedlings established on an agricultural field. Scandinavian Journal of Forest Research 9: 347–359.

Ferrand, J. Ch. 1982. Growth stresses and silviculture of eucalypts. Australian Forest Research 13: 75–81.

Fjærtoft, F. & Bunkholt, A. 1994. Sorteringsreglement for tømmer og trelast av bjørk, -resultater fra skurforsøk. Summary: Grading rules for sawlogs of birch – results of sawing experiments. Research Paper of Skogforsk 18/94: 1–22. Norwegian Forest Research Institute & Department of Forestry, Agricultural University of Norway. Ås-NLH, Norway.

Fries, J. 1964. Vårtbjörkens produktion i Svealand och Södra Norrland. Summary: Yield of Betula verrucosa Ehrh. in Middle Sweden and Southern North Sweden. Studia Forestalia Suecica 14. 303 p.

Häggman, H. 1998. Geenitekniikkatutkimus pohjana metsäpuiden molekyylijalostukselle. Metsätieteen aikakauskirja – Folia Forestalia 2/1998: 235–240. (In Finnish)

Hagqvist, R. 1986. Esimerkkejä koivunjalostuksen parhaista tuloksista. Metsänjalostussäätiö, jalostusosasto. Mimeograph. 2 p. (In Finnish)

— 1998. Jalostettu koivu kasvultaan ja laadultaan selvästi metsikköalkuperiä parempaa. Summary: New results on breeding gains with birch. In: Napola, J. (ed.). Foundation for Forest Tree Breeding. Annual Report 1997. p. 10–17, 28–29.

Hakkila, P. 1962. Polttohakepuun kuivuminen metsässä. Summary: Forest seasoning of wood intended for fuel chips. Communicationes Instituti Forestalis Fenniae 54(4). 82 p.

— 1963. Koivujen kuivuminen rasissa ja niistä tehtyjen pinotavarapölkkyjen vettyminen uitossa. Summary: The seasoning of leaf-felled birches and the waterlogging of cordwood of leaf-felled birches in floating. Communicationes Instituti Forestalis Fenniae 57(3). 32 p.

— 1966. Investigations on the basic density of Finnish pine, spruce and birch wood. Communicationes Instituti Forestalis Fenniae 61(5). 59 p.

— 1979. Wood density survey and dry weight tables for pine, spruce and birch stems in Finland. Communicationes Instituti Forestalis Fenniae 96(3). 59 p.

— , Heikkilä, P. & Michelsen, P. 1970. Vanerikoivujen rasiinkaatokausi. Summary: Leaf-seasoning in veneer birch logging. Communicationes Instituti Forestalis Fenniae 70(2). 42 p.

Hallaksela, A.-M. & Niemistö, P. 1998. Stem discoloration of planted silver birch. Scandinavian Journal of Forest Research 13: 169–176.

Hämet-Ahti, L., Palmén, A., Alanko, P. & Tigerstedt, P.M.A. 1989. Suomen puu- ja pensaskasvio. Dendrologian Seura – Dendrologiska Sällskapet r.y., Helsinki. 290 p. (In Finnish)

Heikinheimo, O. 1915. Kaskiviljelyksen vaikutus Suomen metsiin. Acta Forestalia Fennica 4. 472 p. (In Finnish)
— 1917. Metsien uudistaminen vesojen avulla. Tapio. p. 33–38, 73–78. (In Finnish)
Heikurainen, L. 1959. Koivukysymys ojitetuilla soilla. Metsätaloudellinen Aikakauslehti 9: 318–321. (In Finnish)
Heiskanen, V. 1957. Raudus- ja hieskoivun laatu eri kasvupaikoilla. Summary: Quality of the common birch and the white birch on different sites. Communicationes Instituti Forestalis Fenniae 48(6). 99 p.
— 1958. Koivupinotavaran kuivuminen ja säilyminen metsävarastoissa. Pienpuualan toimikunnan julkaisu 64. Helsinki. (In Finnish)
— 1959. Halkaistun, aisatun ja kuorellisen koivupinotavaran kuivuminen ja säilyminen metsävarastoissa. Summary: Drying and storage of forest-stored split, strip-barked, and unbarked birch cordwood. Communicationes Instituti Forestalis Fenniae 50(7). 63 p.
— 1966. Tutkimuksia koivujen vikaisuuksista, niiden vaikutuksesta sorvaustulokseen sekä niiden huomioonottamisesta laatuluokituksessa. Summary: Studies on the defects of birch, their influence on the quality and quantity of rotary cut veneer, and their consideration in veneer birch grading. Acta Forestalia Fennica 80. 128 p.
— & Salmi, J. 1976. Koivutukkien latvamuotoluvut ja yksikkökuutiot. Summary: Top form factors and unit volumes of birch logs. Folia Forestalia 287. 46 p.
Henningson, B. 1964. Utbyte och kvalitet hos sulfatmassa framställd av rötskadad tall-, gran- och björkved. Summary: Yield and quality of sulphate pulp prepared from decayed pine, spruce, and birch pulpwood. Skogshögskolan, Institutionen för Virkeslära, Rapporter och Uppsatser, Rapport R48: 1–18.
— 1970. Utbyte och egenskaper hos sulfatmassa framställd av skogslagrad björk- och aspmassaved. Summary: Yield and Properties of Sulphate Pulp from Forest Stored Birch and Aspen Pulpwood. Skogshögskolan, Institutionen för Virkeslära, Rapporter och Uppsatser, Rapport R64: 1–64.
Heräjärvi, H. 1999. Koivun sahaus kannattavammaksi. Puumies 4: 17–18. (In Finnish)
— & Varis, N. 2000. Lyhyitä tukkeja koivusahoille – mitä hyötyä? Puumies 3: 12–13. (In Finnish)
— , Verkasalo, E., Kaurala, H. & Lehtimäki, J. 2000. Properties and utilisation of birch (Betula pendula, B. pubescens) for sawmilling and further processing in Finland. In: Usenius, A. & Kari, P. (eds.). Proceedings of COST Action E10 ood Properties for Industrial Use, Third orkshop on Measuring of ood Properties, rades and Qualities in the Conversion Chains and lobal ood Chain Optimisation, 19th–21st June, 2000, Dipoli, Espoo, Finland. p. 83–102.
Hoadley, R.B. 1980. Understanding wood. A craftsman s guide to wood technology. A Time oodworking Book. The Taunton Press, Inc. Newton, Connecticut. 256 p.
Isomäki, O. & Leppänen, H. 1992. Koivu- ja koivuaihioiden laatuluokitus. Puumies 4: 24–25. (In Finnish)
— & Myllynen, T. 1992. Huonekalujen ja komponenttien pintojen laatu. Puumies 4: 24–25. (In Finnish)
Jalava, M. 1938a. Vanerikoivujen arvosuhteista. Puuteknillinen tutkimuslaitos, Puun hankinta- ja kuljetusosasto, Tiedotus VT. 8. Otaniemi. (In Finnish)
— 1938b. Vanerikoivujen kaato ja uitto. Puutekniikan tutkimuksen kannatusyhdistyksen julkaisu 28. Helsinki. 50 p. (In Finnish)
— 1943. Huonekaluteollisuuteen käytettävän koivusahatavaran laatuvaatimuksista. Metsätaloudellinen Aikakauslehti 60: 248–249. (In Finnish)
— 1945. Suomalaisen männyn, kuusen, koivun ja haavan lujuusominaisuuksista. Summary: Strength properties of Finnish pine, spruce, birch and aspen. Communicationes Instituti Forestalis Fenniae 33(3). 66 p.
— 1949. Koivun ja koivuteollisuuden merkitys Suomessa. Metsätaloudellinen Aikakauslehti 66(12) (nr 1): 3–6. (In Finnish)
— 1957. Vaneriteollisuus. Julkaisussa: Metsäkäsikirja, 2. osa. Kustannus Oy Kivi, Helsinki. p. 877–888. (In Finnish)
Jensen, . 1950. Studium av björkens anatomi. Paperi ja Puu B, 4a: 7–10 23 pictures. (In Swedish)
— 1953. Björk ur teknisk och kemisk synpunkt. ä bo Akademi, Institutet för träkemi, Meddelande 143. 7 p. (In Swedish)
Johansson, J. 1996. Färgförändringar av björkvirke vid konventionell varmluftstorkning i kammartork. M.Sc. thesis. Luleö Tekniska Universitet, Inst. Skellefteö. (In Swedish)
Jouhtinen, T. 1994. Koivusahatavaran laatuluokitus. Insinöörityö. Lahden teknillinen oppilaitos, Julkai-

susarja, Raportti 6. (In Finnish)
Junckers Industrier – tanskalainen metsäteollisuusjätti. 1992. Puumies 6: 12–14. (In Finnish)
Juutinen, P., Kurkela, T. & Lilja, S. 1976. Ruohokaskas, Cicadella viridis (L.), lehtipuun taimien vioittajana sekä vioitusten sienisaastunta. Summary: Cicadella viridis (L.) as a wounder of hardwood saplings and infection of wounds by pathogenic fungi. Folia Forestalia 284. 12 p.
Juva, A. & Ahtorinne, M. 1995. Suomen huonekaluteollisuuden kilpailukyky, mahdollisuudet ja keinot. Suomen Ulkomaankauppaliiton julkaisusarja 11. Finnish Foreign Trade Association, Market Information Service. (In Finnish)
Juvonen, R. & Kariniemi, J. 1984. Vaneriteollisuus. Mekaaninen metsäteollisuus 1. Ammattikasvatushallitus – Suomen puuteollisuusinsinöörien yhdistys ry, Helsinki. 189 p. (In Finnish)
Jørgensen, P. F., Tronstad, S. & Tengs, A. 1995. Tørking av bjørk. KanEnergi og Norsk Treteknisk Institutt, Rapport 29. Oslo. 46 p + app 10 p. (In Norwegian)
Kangas, E. 1935. Die Braunfleckigkeit des Birkenholzes und ihr Uhrheber Dendromyza (Bizygomyza) betulae N. sp. Communicationes Instituti Forestalis Fenniae 22(1). 31 p. (In German with Finnish summary)
Kärki, T. 1997. Sahauskelpoisen erikoispuun laatuvaatimukset ja käyttö Savo-Karjalan alueella. Metsätieteen aikakauskirja – Folia Forestalia 1/1997: 37–48. (In Finnish)
Kärkkäinen, M. 1978a. Käytännön tuloksia koivuviilun saannosta. Abstract: Empirical results on birch veneer yield. Folia Forestalia 368. 16 p.
— 1978b. Viilusaannon teoreettinen malli. Abstract: Theoretical model for the veneer yield. Communicationes Instituti Forestalis Fenniae 95(2). 42 p.
— 1979. Koivutukkien tarkistusmittauksia. Abstract: Control measurements of birch logs. Folia Forestalia 377. 21 p.
— 1980. Havaintoja koivutukkien epäpyöreydestä ja pituusmittaeroista. Summary: Observations on the out-of-roundness and deviations from nominal lengths of birch logs. Silva Fennica 14: 286–293.
— 1984. Miten koivuun tulisi suhtautua metsätaloudessa. Summary: The proper attitude towards birch in forestry. Silva Fennica 18(1): 71–100.
— 1986. Koivuvaneritukkien ja -runkojen arvosuhteet. Summary: Value relations of birch veneer logs and stems. Silva Fennica 20(1): 45–57.
— 1991. Industriell användning av björk i Finland. Skogskonferensen 1989, Ultuna 5.12.–6.12. Björk och asp. Skogsfakta 15: 56–59. (In Swedish)
— 1998. Koivu ennen ja nyt. In: Niemistö, P. & Väärä, T. (eds.). Rauduskoivu tänään – ja tulevaisuudessa. Tutkimuspäivä Tampereella 12.3.1997. Metsäntutkimuslaitoksen tiedonantoja 668. p. 1–4. (In Finnish)
— & Raivonen, M. 1977. Reaktiopuun mekaaninen lujuus. Summary: Mechanical strength of reaction wood. Silva Fennica 11: 87–96.
Kataikko, M.-S. 1996. Huonekaluvalmistajien tarpeet sahaamisen lähtökohtana. Taitemia 5. Kuopion Käsi- ja Taideteollisuusakatemia. 126 p. + app. 41 p. (In Finnish)
Kauppi, A. 1989. Sprouting in birches. A morphological and ecophysiological approach. Acta Univ. Ouluensis, Ser. A 209. Dissertation.
Keinonen-Mettälä, K. & von Weissenberg, K. 1999. Improved method for agrobacterium-mediated gene transfer in silver birch (Betula pendula). Plant Cell, Tissue and Culture. In press.
Keinänen, E. & Tahvanainen, V. 1995. Pohjolan jalot puut. Erikoispuiden mitta-, laatu- ja käsittelyopas. Taitemia-sarja. Kuopion käsi- ja taideteollisuusakatemia. 160 p. (In Finnish)
Kellomäki, S. & Salmi 1979. Koivuvaneritukkien kuoren määrä. Summary: Bark quantity of birch logs. Folia Forestalia 413. 16 p.
Kivimaa, E. 1952a. Leikkuuvoima puun työstössä. Paperi ja Puu 34: 253–262. (In Finnish)
— 1952b. Leikkuuvoima puun työstössä. Paperi ja Puu 34: 307–313. (In Finnish)
— 1952c. Leikkuuvoima puun työstössä. Paperi ja Puu 34: 332–341. (In Finnish)
— 1952d. Leikkuuvoima puun työstössä. Paperi ja Puu 34: 382–389. (In Finnish)
Kivistö, J., Sipi, M., Kantola, A. & Niemelä, T. 1999. Koivun, haavan ja harmaalepän mekaaninen jalostus ja lopputuotteet Suomessa vuonna 1999. Postikysely- ja haastattelututkimuksen tulosten yhteenveto. Helsingin yliopiston metsävarojen käytön laitoksen julkaisuja 20. 56 p. + app. (In Finnish with English abstract)
Kohmo, I. 1984. Lehtipuuston runkolukusarjat Etelä-Suomen piirimetsälautakuntien alueilla 1977–1982. Summary: Statistics on the deciduous growing stock in the forestry board districts of South Finland during the period 1977 to 1982. Folia Forestalia 582. 19 p.

Koivisto, P. 1958a. Koivikon kasvatuksesta ja tuotoksesta. Metsätaloudellinen Aikakauslehti 1958: 88–93. (In Finnish)
— 1958b. Etelä-Suomen hoidettujen raudus- ja hieskoivikoiden kehityksestä. University of Helsinki, Department of Forest Estimation. 158 p. (In Finnish)
— 1959. Kasvu- ja tuottotaulukoita. Summary: Growth and yield tables. Communicationes Instituti Forestalis Fenniae 51(8). 49 p.
— 1966. Itä- ja Pohjois-Hämeen koivuvarat. Summary: Birch resources in the forestry board districts of Itä-Häme and Pohjois-Häme. Folia Forestalia 24. 11 p.
— 1968. Etelä- ja Pohjois-Karjalan, Itä-, Etelä- ja Pohjois-Savon sekä Keski-Suomen koivuvarat. Summary: Birch resources in forestry board districts of Etelä- and Pohjois-Karjala, Itä-, Etelä- and Pohjois-Savo and Keski-Suomi. Folia Forestalia 45. 15 p.
Koivua vientiin Viitasaarelta. 1988. Maaseudun Tulevaisuus 72(86): 27. (In Finnish)
Koivumäki 1992. Koivuraaka-aineen viat valmistajan näkökannalta. Puumies 7(10): 296–300. (In Finnish)
Koivutukin lajittelu ja särmäämättömän koivusahatavaran laadut. 1988. Vilkonsaha Oy, Hirvensalmi. 2 p. (In Finnish)
Kollman, F.F.P. & Côté, W.A. 1984. Principles of wood science and technology. Volume I: Solid wood. Springer-Verlag, Berlin. 502 p.
Koponen, H. 1995. Puulevytuotanto. Gummerus. Saarijärvi. 212 p. (In Finnish)
Kučera, B. 1980. Fysiske og anatomiske egenskaper hos lavlandsbjørk. Norges landbruksvidenskaplige forskningsråd, Sluttrapport 343. Oslo. 15 p. (In Norwegian)
— 1983. Kvalitetskrav til skurlast av lauvtre. Abstract: Quality specifications for sawnwood of broadleaved species. Agricultural University of Norway, Department of Wood Technology. Ås-NLH. 19 p.
— 1984. Björkevirkets mekaniske, teknologiske og fysiske egenskaper. Norges landbruksvidenskaplige forskningsråd, Sluttrapport 500. Oslo. 20 p. (In Norwegian)
— & Christiansen, T. 1985. Rapport fra kollokvium om kvalitetskrav til skurtømmer og spesialtømmer av lauvtrær. Norges landbrugshøgskole, Institutt for treteknologi. Ås-NLH. 22 p. + app. (In Norwegian)
— & Myhra, H. H. 1996. Egenskaper hos de viktigste norske lauvtrær. Norsk Treteknisk Institutt, Rapport 33. Oslo. 58 p. (In Norwegian)
Kujala, V. 1946. Koivututkimuksia. Summary: Some recent research data on birches. Communicationes Instituti Forestalis Fenniae 34(1). 34 p.
Kurkela, T. 1977. Rauduskoivun viljelystä ja sitä haittaavista tuhoista. Metsä ja Puu 12: 11–13. (In Finnish)
Laaksonen, M. & Rajala, A. 1987. Suomen huonekaluteollisuuden rakenne ja toimintatavat. Summary: Structural characteristics and modes of activity of Finnish furniture industry. Vaasan kauppakorkeakoulun julkaisuja, Tutkimuksia 128. Liiketaloustiede 40, Markkinointi. 178 p. + app.
Lähde, E. & Raulo, J. 1977. Eri kehitysvaiheessa istutettujen rauduskoivun taimien viljelyn onnistuminen auratuilla uudistusaloilla Pohjois-Suomessa. Summary: Development of silver birch (Betula pendula Roth) seedlings outplanted at different developmental stages on plowed reforestation areas in North Finland. Communicationes Instituti Forestalis Fenniae 91(6). 30 p.
Lahti, A. 1991. Pohjoismaisen huonekaluteollisuuden kilpailuasetelma. Helsinki School of Business Economics. F-289. 24 p. (In Finnish)
Langhammer, A. 1982. Vekstudier på hengebjørk (Betula verrucosa Ehrh.) i Norge. Summary: Growth studies on silver birch (Betula verrucosa Ehrh.) in Norway. Norges Landbrukshögskole, Melding 61(23): 1–43.
Lappi-Seppälä, M. 1933. Faneeritukin käyttöarvoon vaikuttavista vikanaisuuksista ja virheettömän faneeripuun kasvatuksesta. Suomen Puu 6, 7. 6 p. Reprint. (In Finnish)
Larson, T.D., Erickson, R.W. & Boone, R.S. 1986. Comparison of drying methods for paper birch SDR flitches and studs. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Research Paper FPL-465. Madison, Wisconsin. 13 p.
Lehonkoski, N.A. 1937. Koivu faneeriteollisuuden raaka-aineena. Yksityismetsänhoitajayhdistyksen vuosikirja X. p. 75–84. (In Finnish)
— 1949. Vanerikoivujemme nykyinen laatu. Metsätaloudellinen Aikakauslehti 66(12) (nr 1): 16–18. (In Finnish)
Leikola, M. 1976. Maanmuokkaus ja pintakasvillisuuden torjunta peltojen metsittämisessä. Summary: Soil tilling and weed control in afforestation of abandoned fields. Communicationes Instituti Fore-

stalis Fenniae 88(3). 101 p.
Lepistö, M. 1970. "Märän maan koivujakin" jalostetaan. Metsälehti 41(50): 2. (In Finnish)
— 1981. Koivunjalostuksen tulokset varmistuvat. Summary: Promising results from Finnish birch (B. pendula) progeny tests. The Foundation for Forest Tree Breeding in Finland, Information 2/1981. 8 p.
Leppänen, H. 1992. Koivumateriaalien laatuluokitus. Lahti Polytechnic Institute, Publication Series, Report 2. (In Finnish)
Levlin, J.-E. 1986. Koivu vai eukalyptus? Paperi ja Puu – Papper och Trä 11: 776–777. (In Finnish)
Liepins, R. 1933. Die technischen Eigenschaften der Birke Lettlands. Commentations Forestales 6: 1–15. Helsinki, Finland. (In German with Finnish summary)
Liiri, O. 1960. Tutkimuksia lastulevyteollisuuden puuraaka-aineista I. Suomalaiset puulajit lastulevyn raaka-aineina. The State Technical Research Institute of Finland, Information Series I – Wood 17. 41 p. Otaniemi. (In Finnish)
Louna, T. & Valkonen, S. 1995. Kotimaisen raaka-aineen asema lehtipuiden teollisessa käytössä. Metsäntutkimuslaitoksen tiedonantoja 553. 38 p. (In Finnish)
Lukkala, O.J. 1931. Metsäojituksen oppikirja. Keskusmetsäseura Tapio, Helsinki. 258 p. (In Finnish)
Luostarinen, K. & Luostarinen, J. 2000. Discolouration and deformations of birch parquet boards during conventional drying. Manuscript. Accepted in Wood Science and Technology.
Maila on merkkituote. 1990. Puumies 1: 3–4. (In Finnish)
Mäkelä, M. 1993. Vanerikoivun koneellinen hakkuu. Abstract: Mechanized cutting of veneer birch. Metsäteho Review 2/1993. 6 p.
— 1994. Koivuvaneritukkien varastoinnin ja hakkuumenetelmän vaikutus raaka-aineen laatuun ja arvoon. Abstract: Influence of storage and harvesting method on the quality and value of birch veneer logs. Metsäteho Review 14/1994. 8 p.
Mali, J. 1980. Kotimaisten puulajien ja tuontipuulajien tekniset ominaisuudet ja käyttö. VTT Julkaisuja – Publikationer 3. 43 p + app. (In Finnish)
Marjomaa, J. 1992. Puutavaralajien tuoretiheyksien vaihtelu. Abstract: Variations in the weight of timber assortments. Metsäteho Review 4/1992. 8 p.
Mätningsinstruktioner för sågtimmer av björk, klibbal eller asp. 1987. In: Mätningsinstruktioner rekommenderade av virkesmätningsrådet. Virkesmätningsrådet, Meddelande 1-87. p. 26–29. (In Swedish)
Meriluoto, J. 1966. Raaka-ainetekijöiden vaikutus sorvatun koivuviilun määrään ja laatuun. Summary: The influence of raw material factors on the quantity and quality of rotary cut birch veneer. Acta Forestalia Fennica 80(1). 55 p.
Messier, C. & Puttonen, P. 1995. Growth, allocation, and morphological responses of Betula pubescens and Betula pendula to shade in developing Scots pine stands. Canadian Journal of Forest Research 25: 629–637.
Metsäliitto hankkii erikoiskoivua Tiwille. 1997. Metsäliiton Viesti 1: 21–22. (In Finnish)
Mielikäinen, K. 1980. Mänty-koivusekametsiköiden rakenne ja kehitys. Summary: Structure and development of mixed pine and spruce stands. Communicationes Instituti Forestalis Fenniae 99(3). 82 p.
— 1985. Koivusekoituksen vaikutus kuusikon rakenteeseen ja kehitykseen. Summary: Effect of an admixture of birch on the structure and development of Norway spruce stands. Communicationes Instituti Forestalis Fenniae 133. 79 p.
Mikkola, E. (ed.). 1997. Metsätilastollinen vuosikirja – Yearbook of Forest Statistics 1996. SVT, Maa- ja metsätalous – Finnish Official Statistics, Agriculture and Forestry 1996: 3. 352 p.
— & Kulju, I. (eds.) 1994. Raakapuun vienti ja tuonti maittain tammi-joulukuu 1993. Finnish Forest Research Institute, Department of Forest Utilisation, Timber Market Communication 617. 6 p. (In Finnish)
Mikola, P. 1942. Koivujen vesomisesta ja sen metsänhoidollisesta merkityksestä. Referat: Über die Ausschlagbildung bei der Birke und ihre forstliche Bedeutung. Acta Forestalia Fennica 50(3). 102 p. (In Finnish with German summary)
Minkkinen, T. 1992. Mikrolisättyjen rauduskoivun taimien alkukehitys taimitarhalla. Pro gradu -thesis. University of Joensuu, Faculty of Forestry. (In Finnish)
Moilanen, M. 1985. Lannoituksen ja harvennuksen vaikutus hieskoivun kasvuun ohutturpeisilla ojitetuilla rämeillä. Summary: Effect of fertilization and thinning on the growth of birch (Betula pubescens) on the drained mires with thin peatlayer. Folia Forestalia 629. 29 p.
Nagoda, L. 1969. Vanningholdets variasjon i stam-

metverrsnittet av bjørk (Betula verrucosa) og svartor (Alnus glutinosa). Tidskrift for Skogbruk 77(3): 383–396. (In Norwegian with English summary)

Nepveu, G. & Velling, P. 1983. Rauduskoivun puuaineen laadun geneettinen vaihtelu. Summary: Individual genetic variability of wood quality in Betula pendula. Folia Forestalia 575. 21 p.

Niemistö, P. 1994. Vuonna 1964 viljeltyjen rauduskoivujen värivioista. Finnish Forest Research Institute, Muhos Research Station. Manuscript. 5 p. (In Finnish)

— 1995a. Influence of initial spacing and row-to-row distance on the crown and branch properties and taper of silver birch (Betula pendula). Scandinavian Journal of Forest Research 10: 235–244.

— 1995b. Influence of initial spacing and row-to-row distance on growth and yield of silver birch (Betula pendula). Scandinavian Journal of Forest Research 10: 245–255.

— 1998a. Ruskotäplät istutettujen rauduskoivujen rungoissa. Metsätieteen aikakauskirja – Folia Forestalia 2/1998: 133–149. (In Finnish)

— 1998b. Istutuskoivun ulkoinen laatu pelto- ja metsämailla. In: Niemistö, P. & Väärä, T. (eds.). Rauduskoivu tänään – ja tulevaisuudessa. Tutkimuspäivä Tampereella 12.3.1997. Metsäntutkimuslaitoksen tiedonantoja 668. p. 103–114. (In Finnish)

— , Hukki, P. & Verkasalo, E. 1998. Kasvupaikan ja puuston tiheyden vaikutus rauduskoivun ulkoiseen laatuun 30-vuotiaissa istutuskoivikoissa. Metsätieteen aikakauskirja – Folia Forestalia 3/1997: 349–374. (In Finnish)

Ohman, J.H. 1970. Value loss from skidding wounds in sugar maple and yellow birch. Journal of Forestry 68: 226–230.

Oikarinen, M. & Pyykkönen, J. 1981. Harvennuksen ja lannoituksen vaikutus turvekankaan hieskoivikon kehitykseen. Abstract: The effect of thinning and fertilization on the growth of pubescent birch (Betula pubescens) on drained Myrtillus spruce swamp in Ostrobothnia. Folia Forestalia 486. 15 p.

Olavinen, O. (ed.). 1964. Vaneriteollisuus. In: Heikinheimo, O. (ed.). Mekaaninen puuteollisuus I, 3: 388–645. Association of the Finnish Wood Engineers. (In Finnish)

Ollinmaa, P. 1955. Koivun vetopuun anatomisesta rakenteesta ja ominaisuuksista. Summary: On the anatomic structure and properties of the tension wood in birch. Acta Forestalia Fennica 64(3). 263 p.

— 1956. Vetopuun rakenteesta ja ominaisuuksista. Paperi ja Puu 12: 603–611. (In Finnish)

— 1958. Vertailevia tutkimuksia puusyiden pituudesta hieskoivun kevät- ja kesäpuussa. Paperi ja Puu 11: 599–601. (In Finnish)

— 1960. Eräistä ojitetuilla soilla kasvavan puun fysikaalisista ominaisuuksista. Summary: On certain properties of wood growing on drained swamps. Acta Forestalia Fennica 72(2). 24 p.

Paasonen, P.K. 1967. The location and behaviour of birch extractives in the cell system of the tree. Paperi ja Puu 49(8): 503–508.

Paavilainen, E. & Norlamo, M. 1975. Effect of various nitrogen fertilizers on the initial development of birch, spruce and pine. Communicationes Instituti Forestalis Fenniae 86(2). 43 p.

Pajuoja, H. & Suihkonen, V. 1994. (eds.). Raakapuun käyttö Suomessa vuonna 1993. Finnish Forest Research Institute, Department of Forest Utilisation, Forest Statistics Communication 229. 7 p.

Pakkanen, M., Virtanen, J. & Paajanen, T. 1998. Raaka-aineen saatavuus ja potentiaali sahatavaran jalostukseen Suomessa. Abstract: Availability and potential of the raw material to refining of sawn timber in Finland. Helsinki University of Technology, Wood Technology, Report 76. 85 p.

Paukkonen, K. & Kauppi, A. 1998. Effect of coppicing and root pruning on structural root growth and morphology and their significance for subsequent shoot regeneration of birches. Canadian Journal of Forest Research 28: 1780–1787.

— & Luostarinen, J. 1999. Koivusahatavaran värinmuutokset kuivattaessa. Puumies 3/1999: 18, 20.

— , Luostarinen, J., Asp, J. & Asikainen, A. 1999. Koivusahatavaran muodon- ja värinmuutokset kuivauksessa. Metsätieteen aikakauskirja 2/1999: 227–238. (In Finnish)

Pekkala, O. & Uusvaara, O. 1980. Kuitupuun metsävarastoinnin vaikutus massan saantoon ja laatuun. Summary: Storage of pulpwood in the forest and its effect on the yield and quality of pulp. Communicationes Instituti Forestalis Fenniae 96(4). 24 p.

Perilä, O. 1954. Koivun (Betula verrucosa) runkosolukon hartsi-, rasva- ja vahamaisten aineiden sijainti. Paperi ja Puu 36: 213–216. (In Finnish)

— & Toivonen, A. 1958. Investigations concerning the seasonal fluctuation in the composition of the diethylether extract of birch (Betula verrucosa). Paperi ja Puu 40(4a): 207–213.

Peterson, O. & Winqvist, T. 1960. Vikt- och fuktighets-variationer hos björk under olika årstider. Summary: Variation in weight and moisture content of birch wood between different seasons. Skogshögskolan, Institutionen för Virkeslära, Rapporter och Uppsatser, Rapport R28: 1–60.

Polge, H. 1981. Influence des éclaircies sur les contraintes de croissance du hêtre. Annales des Sciences Forestières 38: 407–423. (In French)

Rantanen, A., Jalonen, O.P. & Pitkänen, P.S. 2000. Etelä-Savon lehtipuuvarojen teknis-taloudellinen hyödyntäminen. Helsingin yliopiston maaseudun tutkimus- ja koulutuskeskus, Mikkeli, Julkaisuja 72. 47 p. (In Finnish)

Raulo, J. 1978. Forestation chain for birch (Betula pendula Roth) in Finland. Seloste: Rauduskoivun (Betula pendula Roth) viljelyketju Suomessa. Silva Fennica 12(1): 17–24.

— 1979. Rauduskoivujälkeläistöjen rungon laatu Etelä- ja Keski-Suomessa. Summary: Stem quality of Betula pendula Roth progenies in South and Central Finland. Communicationes Instituti Forestalis Fenniae 97(5). 21 p.

— 1981. Koivukirja. Gummerus, Jyväskylä. 131 p. (In Finnish)

— & Koski, V. 1977. Growth of Betula pendula Roth progenies in Southern and Central Finland. Communicationes Instituti Forestalis Fenniae 90(5). 39 p.

— & Lähde, E. 1976. Ennakkotuloksia rauduskoivun kylvökokeista Lapissa. Summary: Preliminary results on sowing experiments with Betula pendula Roth in Finnish Lapland. Folia Forestalia 279. 11 p.

— & Lähde, E. 1977. Rauduskoivun istutustuloksia Lapissa. Summary: Reforestation results with Betula pendula in Finnish Lapland. Folia Forestalia 325. 10 p.

— & Lähde, E. 1981. Rauduskoivun kylvökokeita Lapissa. Summary: Sowing experiments with Betula pendula in Finnish Lapland. Folia Forestalia 461. 12 p.

— , Lähde, E. & Rokkonen, J. 1998. Koivun uudistamis- ja kasvatuskokeita ja niiden tuloksia. Metsäntutkimuslaitoksen tiedonantoja 669. 69 p. (In Finnish)

Redner, R. & Rognerud, P.A. 1991. Bruk bjørk. Det Norske Skogselskap, Skogforsk, Treopplysningsrådet. 17 p. (In Norwegian)

Rintala, P. 1995. Rauduskoivun pystykarsintavikojen yhteys karsittavien oksien kokoon ja laatuun sekä karsintavuodenaikaan. Pro gradu -thesis. University of Joensuu, Faculty of Forestry. 105 p. (In Finnish)

Ronkanen, A.J. 1949. Vaneripuurunkojen apteeraus. Metsätaloudellinen Aikakauslehti 66(12) (nro 1): 27–28.

— 1968. Koivu ja sen teollinen käyttö 1900-luvulla. Puumies 6: 158–159. (In Finnish)

Runqvist, E. & Thunell, B. 1945. Undersökningar över några virkesegenskaper hos björk. Svenska Träforskningsinstitutet, Trätekniska avdelningen, Meddelande 7. 11 p. (In Swedish)

Sachsse, H. 1988. Holzqualität von Birken. Die Baumart Birke und ihre anatomischen Holzeigenschaften. Abstract: Wood quality of birches. The tree species birch and its anatomical wood properties. Holz als Roh- und Werkstoff 46: 441–446.

— 1989. Holzqualität von Birken. Strukturelle und physikalisch-mechanische Eigenschaften von Birkenhölzern. Abstract: Wood quality of birches. Structural and physical-mechanical properties of birch timber. Holz als Roh- und Werkstoff 47: 27–30.

Sahakoivun ja erikoiskoivutukin laatuvaatimukset. 1988. Vilkonsaha Oy, Hirvensalmi. 2 p. (In Finnish)

Sahakoivun ja erikoiskoivutukin laatuvaatimukset, koivutukin lajittelu ja särmäämättömän koivusahatavaran laadut. 1998. Vilkon Oy, Hirvensalmi, Finland. 4 p. (In Finnish)

Saikku, O. 1975. Typpilannoituksen vaikutuksesta männyn, kuusen ja koivun puuaineen tiheyteen. Summary: The effect of nitrogen fertilization on the basic density of Scots pine (Pinus sylvestris), Norway spruce (Picea abies) and common birch (Betula verrucosa). Acta Forestalia Fennica 85(5). 24 p.

Saimovaara, J. 1994. Puusepänteollisuus. Tapion Taskukirja, 22nd ed. Kustannusosakeyhtiö Metsälehti. p. 561–566. (In Finnish)

Saksa, T. 1998. Rauduskoivun uudistaminen – luontaisesti vai viljellen. In: Niemistö, P. & Väärä, T. (eds.). Rauduskoivu tänään – ja tulevaisuudessa. Tutkimuspäivä Tampereella 12.3.1997. Metsäntutkimuslaitoksen tiedonantoja 668. p. 5–10. (In Finnish)

Salakari, M. & Peltola, A. 1995. Pientalojen polttopuun käyttö lämmityskaudella 1992/93. Metsäntutkimuslaitoksen tiedonantoja 566. 27 p. + app. (In Finnish)

Salmi, J. 1964. Lahovikaisuuden vaikutus koivupuun lämpöarvoon. Pienpuualan toimikunnan julkaisu 168. 26 p. (In Finnish)

— 1987a. Koivun puuaineen ominaisuudet ja käyttö. Abstract: Wood properties and uses of birch, Betula spp. Sorbifolia 18(3): 123–132.

— 1987b. Suomalaisia ja ulkomaisia puulajeja. Osa II: Lehtipuut A-N. Wood of Finnish and foreign tree-species. Volume II: Broad-leaved trees A...N. University of Helsinki, Department of Logging and Utilisation of Forest Products, Research Notes 35. 282 p.

Salo, E. 1954. Puiden teknillinen vikaisuus ja sen vaikutus puuston arvoon. Summary: Technical defects of trees and their effect upon timber values. Acta Forestalia Fennica 61(24). 57 p.

— 1955. Puuston teknillinen vikaisuus ja sen vaikutus puustosta saatavien eri puutavaralajien määrään. Summary: The effect of technical defects upon the amount of timber. Metsätaloudellinen Aikakauslehti 72(18) (no 12): 412–414.

Saramäki, J. 1977. Ojitettujen turvemaiden hieskoivikoiden kehitys Kainuussa ja Pohjanmaalla. Summary: Development of white birch (Betula pubescens Ehrh.) stands on drained peatlands in Northern Central Finland. Communicationes Instituti Forestalis Fenniae 91(2). 59 p.

— 1981. Hieskoivun kasvu ja kasvatus Pohjanmaalla ja Kainuussa. Metsäntutkimuslaitoksen tiedonantoja 3. 37 p. (In Finnish)

— 1994. Onko hieskoivulla paikkaa metsätaloudessa? In: Hannelius, S. (ed.). Metsänkasvatuksen tutkimuspäivä 1993, Järvenpää, 16.11.1993. Metsäntutkimuslaitoksen tiedonantoja 491. p. 19–23. (In Finnish)

Sarvas, R. 1944. Tukkipuun harsintojen vaikutus Etelä-Suomen yksityismetsiin. Summary: Influence of dimension cutting of saw timber on the private-owned forests in Southern Finland. Communicationes Instituti Forestalis Fenniae 33(1). 255 p.

— 1949. Puumaiset koivulajimme. Metsätaloudellinen Aikakauslehti 66(12)(nr. 1): 9–13. (In Finnish)

— 1951. Raudusko vai hies vanerikoivuna parempi? Metsätaloudellinen Aikakauslehti 68(14) (nr. 21–23): 51–53. (In Finnish)

Saurat, J. & Guéneau, P. 1976. Growth stresses in beech. Wood Science and Technology 10: 111–123.

Schulman, E. 1989. Koivun ruskotäpläkärpäsen (Dendromyza betulae E. Kang.) esiintymisestä koivuissa ja sen vaneriteollisuudelle aiheuttamista menetyksistä. Manuscript. (In Finnish)

Sevola, Y. (ed.). 1996. Metsätilastollinen vuosikirja – Yearbook of Forest Statistics 1995. SVT Maa- ja metsätalous – Finnish Official Statistics, Agriculture and Forestry 1996: 3. 351 p.

Siimes, F.E. 1967. The effect of specific gravity, moisture content, temperature and heating time on the tension and compression strength and elasticity properties perpendicular to the grain of Finnish pine, spruce and birch wood and the significance of these factors on checking of timber at kiln drying. VTT Julkaisu – Publication 84: 1–86.

Smith, W.B. & Herdman, D.J. 1996. An investigation of board color and sticker stain in hard maple. In: Cloutier, A., Fortin, Y. & Gosselin, R. (eds.). 5th International IUFRO Wood Drying Conference Proceedings "Quality Wood Drying through Process Modelling and Novel Technologies" August 13–17, 1996, Quebec City, Canada. Forintek Canada Corp.–Université Laval.

Starck, M., Bauch, J. & Simatupang, M.H. 1984. Characteristics of normal and discoloured wood of Ilomba (Pycnanthus angolensis Exell). Wood Science and Technology 18: 243–253.

Steuer, R.W. 1979. Die Rohholzsortierung und die Güteklassen. Holz-Zentralblatt 105(86): 1261–1265. (In German)

Tikka, P.S. 1949. Perä-Pohjolan koivikoiden laadusta. Referat: Über die Beschaffenheit der Birkenbestände in Nord-Finnland. Acta Forestalia Fennica 57(4). 34 p. (In Finnish with German summary)

Tronstad, S. 1993. Tørking – trekvalitet. Norsk Treteknisk Institut, Rapport 17. (In Norwegian)

Tuompo, E. 1988a. Pöllinkeskittimien ominaisuuksien ja puuraaka-aineen muodon vaikutuksesta sorvatun viilun saantoon. Licentiate thesis. Helsinki University of Technology, Wood Technology. (In Finnish)

— 1988b. Viilun sorvauksen simuloinnista. Abstract: On the simulation of rotary-cutting of birch veneer. Helsinki University of Technology, Wood Technology, Publication 50. 51 p.

Vadla, K., Berg, N. & Foslie, M. 1982. Bjørk som materiale og råstoff (En litteraturstudie). Summary: Birch as a raw material and building material (a literature survey). Norsk institutt for skogforskning, Rapport 6/82. Ås-NLH. 60 p.

Vanerikoivun mitta- ja laatuvaatimukset. 1998. Schauman Wood Oy. Mimeograph. 2 p. (In Finnish)

Vaneritutkimuksia I n:o 25. 1937. Puutekniikan tutkimuksen kannatusyhdistys. (In Finnish)

Varis, R. 1997. Puuteollisuusinsinöörien ensimmäiset opinnäytepalkinnot jaettu. Puumies 42(5): 36–37. (In Finnish)

Velling, P. 1979. Puuaineen tiheys kahdessa rauduskoivun jälkeläiskokeessa. Summary: Density of silver birch wood in two progeny trials. Folia Forestalia 416. 24 p.

Verkasalo, E. 1990. Koivu ja haapa mekaanisen metsäteollisuuden raaka-aineena Yhdysvalloissa. Summary: Birch and aspen as a raw material for mechanical forest industries in the United States. Metsäntutkimuslaitoksen tiedonantoja 367. 93 p.

— 1993. Koivupuutavaran vikaantuminen pitkittyneessä metsävarastoinnissa ja sen vaikutus viilun saantoon, laatuun ja arvoon. Summary: Deterioration of birch timber during prolonged storage in the forest and its effect on the yield, quality and value of rotary-cut veneer. Folia Forestalia 806. 31 p.

— 1997a. Evaluating the potential of European white birch (Betula pubescens) for veneer and plywood by timber and wood quality. In: Proceedings of the IUFRO Division 6 WP5.01.04 Biological Improvement of Wood Quality Workshop "Connection between Silviculture and Wood Quality through Modelling and Simulation Software", Kruger National Park, South Africa, 26–31 August, 1996, p. 431–439. INRA-Nancy, France.

— 1997b. Hieskoivun laatu vaneripuuna. Abstract: Quality of European white birch (Betula pubescens Ehrh.) for veneer and plywood. Metsäntutkimuslaitoksen tiedonantoja 632. 483 p + app.

— 1997c. Koivun ominaisuudet ja mahdollisuudet saha- ja huonekalupuuna Suomessa. Literature survey for the Ph.D. studies in wood technology. University of Helsinki, Department of Forest Resource Management. Mimeograph. 49 p. (In Finnish)

— 1998. Raudus- ja hieskoivun laatu puuaineen tiheyden perusteella arvioituna. In: Niemistö, P. & Väärä, T. (eds.). Rauduskoivu tänään ja tulevaisuudessa. Tutkimuspäivä Tampereella 12.3.1997. Metsäntutkimuslaitoksen tiedonantoja 668. p.127–140. (In Finnish)

— & Paukkonen, K. 1997. Koivu sahapuuna. Puumies 1: 17–18. (In Finnish)

— & Rintala, P. 1998. Rauduskoivun pystykarsintavikojen riippuvuus oksien paksuudesta, laadusta ja karsinnan ajankohdasta. Metsätieteen aikakauskirja – Folia Forestalia 2/1998: 151–178. (In Finnish)

Vesterinen, E. 1956. Kelpaavatko koivu ja haapa rakennuspuuksi? Suomen Puutalous 2: 63. (In Finnish)

Viherä-Aarnio, A. 1989. Raudus- ja hieskoivun jalostuksen nykytilanne Etelä-Suomessa. In: Metsäntutkimuspäivä Tuusulassa. Metsäntutkimuslaitoksen tiedonantoja 328. p. 38–53. (In Finnish)

— 1990. Erilaisten hieskoivualkuperien menestyminen Muhoksella – metsänjalostuksen kenttäkoetuloksia. In: Valtanen. J., Murtovaara, I. & Moilanen, M. (eds.). Metsäntutkimuspäivät Oulussa 1989. Metsäntutkimuslaitoksen tiedonantoja 361. p. 27–39. (In Finnish)

Viitaniemi, P. 1996. Tekninen puu: mitä modifioinnilla voidaan saavuttaa? Oral presentation, October 11th, 1996, OTAWOOD 1996, VTT and TKK, Espoo. (In Finnish)

— & Jämsä, S. 1996. Puun modifiointi lämpökäsittelyllä. Summary: Modification of wood with heat treatment. VTT Julkaisuja – Publikationer 814. 57 p.

Vilkonsaha kutsui asiakkaansa tutustumiskäynnille. 1988. Puumies 7–8: 14–15. (In Finnish)

Viro, P.J. 1974. Fertilization of birch. Communicationes Instituti Forestalis Fenniae 81(4). 38 p.

Wagenführ, R. 1996. Holzatlas. VEB Fachbuchverlag Leipzig, 4th ed. 688 p. (In German)

Wallden, P. 1934. Tutkimuksia koivupuun anatoomisen rakenteen ja teknillisten ominaisuuksien keskinäisestä riippuvaisuudesta solumittauksien perusteella. Referat: Untersuchungen über die Abhängigkeit der technischen Eigenschaften vom anatomischen Bau des Birkenholzes nach Zellmessungen. Acta Forestalia Fennica 40(14): 329–366. (In Finnish with German summary)

Wang, T.L. & Tigerstedt, P.M.A. 1996. Growth rates and phenology of fast- and slow-growing families over an entire growth period in Betula pendula Roth. Silvae Genetica 45: 124–129.

Warjus, W. 1946. Koivu. Sen käyttö, kasvatus ja tuoton lisääminen. Suomen metsäyhdistyksen metsätaloudellisen valistustoimiston julkaisuja 2. (In Finnish)

Waugh, G. 1977. Reducing growth stresses in standing trees. Australian Forest Research 7: 215–218.

Willman, B. 1997. Etude du phénomène de discoloration des avives de hêtre lors du séchage. Ecole

Nationale Supérieure des Technologies et Industries du Bois. DEA Science du Bois. 30 p. (In French)

Yazaki, Y., Bauch, J. & Endeward, R. 1985. Extractive components responsible for the discolouration of Ilomba wood (Pycnanthus angolensis Exell). Holz als Roh- und Werkstoff 43: 359–363.

Ylioja, T., Saranpää, P., Roininen, H. & Rousi, M. 1998. Larval tunnels of Phytobia betulae (Diptera: Agromyzidae) in birch wood. Journal of Economic Entomology 91: 175–181.

— , Schulman, E., Rousi, M. & Velling, P. 1995. Susceptibility of white birch (Betula spp.) hybrids to Phytobia fly. Icelandic Agricultural Science 9: 125–133.

Yli-Vakkuri, P. 1961. Koivuvarat ja niiden kehitys metsänhoidon näkökulmasta. Summary: Our birch resources and their development from the silvicultural point of view. Metsä ja Puu 11: 444–446, 455.

Zimmermann, G. 1974. Untersuchungen über Art und Ursachen von Verfärbungen an Bergahorn-Stammholz (Acer pseudoplatanus L.). Forstwissenschaftliches Zentralblatt 93: 247–261.

Zobel, B.J. & van Buijtenen, J.P. 1989. Wood variation – its causes and control. Springer Verlag, Berlin. 363 p.

Total of 254 references

Personal Communications

Harinen, R. Karjalan Puu Ltd. Rääkkylä, Finland.

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Appendix 1. Minimum dimension and quality requirements for birch saw logs and special logs for furniture veneer of Vilkon Ltd. (Sahakoivun... 1988) and for plywood birch of Schauman Wood Ltd. (Vanerikoivun... 1998).

Characteristics	Saw birch [1)]	Special birch [2)]	Plywood birch [3)]
Smallest diameter of log measured from the thinnest side over bark	20 cm	24 cm	18 cm
Largest diameter of log	65 cm	85 cm	65 cm
Length of log	3.1–5.2 m	4.0–5.8 m (2.6 and 2.8 m allowed if the diameter is at least 30 cm)	3.1–7.0 m
Largest diameter and number of knots			
– Sound knots	7 cm / No limitations	Not allowed	7 cm / No limitations
– Dry and decayed knots, tubers	4 cm / No limitations	Not allowed	3 cm / 5 knots
Dead sprouted branches in the top	Not allowed	Not allowed	Not allowed
Groups of knots	Not allowed	Not allowed	Not allowed
Maximal sweepness	Half of the diameter in the top side of the log at the lengths of 1.5 m	2 cm at the length of 1.5 m	At whole the length by diameter class: 18–23 cm: 2 cm 24–35 cm: 4 cm 35+ cm: 5 cm
Slight bends	Allowed	Not allowed	Allowed
Sharp bends, multiple crooks	Not allowed	Not allowed	Not allowed
Soft decay	Not allowed	Not allowed	Not allowed
Largest diameter of hard core decay	4 cm	1/3 of the diameter	1/3 of the diameter
Largest diameter of discoloration	4 cm	1/3 of the diameter	1/3 of the diameter
Surface checks	Not allowed	Not allowed	Not allowed
Felling and heart checks	Not allowed	Not allowed	1/3 of the diameter
Tears in bark	Not allowed	Not allowed	Allowed if not longer than 0.3 m
Scars with hard base	Not allowed	Not allowed	Allowed in one side if not longer than 0.6 m, maximal depth 10 % of the diameter
Scars with decayed base	Not allowed	Not allowed	Not allowed
Deeply folded base (ovality)	...	Not allowed	…
Strange items	Not allowed	Not allowed	Not allowed

Specifications:
- Knots smaller than 5 mm are not counted (1,2,3)
- If a dry or decayed knot shows up when a knot tuber is cut along the surface line, the tuber is determined as a large knot tuber (1,2,3)
- The diameter of knot is measured from their dark part in the direction of the cross section of the log (1,2,3)
- No swellings allowed in connection of covered scar or tear in bark (3)
- Knot group includes at least three large knot tubers and /or knots with a diameter of at least 3 cm, which are located among a 20 cm part of trunk (1,2,3)
- If a trunk part has 2 maximal defects it is not good enough for a log (1,2,3)
- At most 1.5 m trunk part below the minimum quality requirements is allowed in a log if there is wood meeting these requirements at least 1.5 m on both sides of the defective part (rejected saw timber in the middle of the trunk) (3)
- Felled by man and cut by chain saw (1,2)
- No leaf-felling or floated logs (2)

Appendix 2. Quality classes of unedged sawn birch timber of Vilkon Ltd. at the beginning of the 1990's (Koivutukin... 1988):

AS	Thickness 19–32 mm, mainly knotless sideboard, a few pearl knots are allowed as well as 1–2 sound knots at the top side of the board, sorted as sawn timber
A1	Thickness 19–25 mm, sawed from grade A logs, includes boards sorted out of grade AS, no boards sawed from the core, sorted as sawn timber
A2	Thickness 32–75 mm, sawed from grade A logs, sawed as two or three pieces, grade B and C pieces are sorted out of the grade A2 as sawn timber
ST	Thickness 19–75 mm, sawed from grade A or B logs, grade C pieces are sorted out as sawn timber
B	Thickness 19–75 mm, sawed from grade B logs, includes pieces sorted out of grade A, grade C pieces are sorted out as sawn timber
Measuring:	Thickness 19–32 mm: the narrower flat is measured from the middle of the sawn piece of timber. Thickness 38–75 cm: As an average of a narrower and broader flats from the middle of the timber piece, so-called cross-measure.

Appendix 3. Average anatomical, physical, mechanical and chemical properties of birch wood compared to beech, oak and spruce. The value in the middle is the average and the right and left values are the extremes (Wagenführ 1996). Spruce is an example of a typical tree species used for building, beech is another species corresponding to birch according to its use for mechanical forest products, and oak is a valuable species for furniture and interior decoration. The chemical values for birch reaction wood are by Ollinmaa (1955).

Characteristics	Silver birch *Betula pendula*	Norway spruce *Picea abies*	Beech *Fagus sylvatica*	Pedunculate oak *Quercus robur*
Structure				
Fibers				
Length, mm	0.34–1.0–1.7	1.3–2.8–4.3	0.6–1.3	1.2–1.5–1.7
Thickness of cell wall (2W), µm	4.2–5.3–6.7	1.9–3.5–4.9 [1)] 9.3–10.7–11.6 [2)]	3.6–7.5–10.3	5.0–6.8–8.7
Diameter of lumen (L), µm	4.0–8.5–14.5	16.0–32.0–45.0 [1)] 6.4–17.4–22.0 [2)]	3.5–7.1–11.2	5.3–7.0–9.2
Volumetric percentage	59.6–64.8–68.1	94.5–95.3–96.5	25.2–39.6–57.2	40.3–44.3–50.0 [3)] 53.5–58.1–63.3 [4)]
Vessels				
Diameter, µm	30–90–130		8–45–85	150–270–350 [1)] 30–70–140 [2)]
Occurrence, no/cm^2	40–60		80–125–160	5–8–13
Volumetric percentage	20.8–24.7–29.6		24.6–39.5–52.5	23.5–39.4–43.7 [3)] 3.9–7.7–13.0 [4)]
Longitudinal parenchyma				
Volumetric percentage	2	0.0–1.4–5.8	3.5–5.2–7.0	2.8–4.9–8.1 [4)]
Rays				
Height, µm/mm	130–240–400	100–150–190	60–500–1000–4000	6–38–80 mm [5)] 80–160–240 µm [6)]
Width, µm	7–15–25	8–14	30–200	500–100 [5)] 8–15–25 [6)]
Occurrence, no/mm	10–17–20	4–5–7	2–3–6–9	1 [5)] 5–9–12 [6)]
Volumetric percentage	9.7–10.5–11.1	4.4–4.7–5.5	11.2–15.7–21.2	14.4–16.2–17.9 [5)] 18.1–29.3–33.0 [6)]

Appendix 3 continued.

Characteristics	Silver birch *Betula pendula*	Norway spruce *Picea abies*	Beech *Fagus sylvatica*	Pedunculate oak *Quercus robur*
Physical properties				
Density, kg/m^3				
Dry-green (ρ_{dgr})	460–610–800	300–430–640	490–680–880	390–650–930
Dry-air dry ($\rho_{12–15}$)	510–650–830	330–470–680	540–720–910	430–690–960
Green (ρ_{gr})	800–850–900	700–800–850	820–1070–1270	650–1000–1160
Shrinkage, %				
Longitudinal (β_l)	0.6	0.3	0.3	0.4
Radial (β_r)	5.3	3.5–3.7	5.8	4.0–4.6
Tangential (β_t)	7.8	7.8–8.0	11.8	7.8–10.0
Volumetric (β_v)	13.7–14.2	11.6–12.0	14.0–17.9–21.0	12.6–15.6
Mechanical properties				
Bending strength (σ_{bB}), MPa	76–147–155	49–78–136	74–123–210	74–88–105
Compression strength (σ_{dB}), MPa	38–51–100	33–50–79	41–62–99	54–61–67
Tensile strength (σ_{zB} II), MPa	35–137–270	21–90–245	57–135–180	50–90–180
Shearing strength (τ_{aB}), MPa	12–4.5	4.0–6.7–12.1	6.5–8.0–19.0	6–11–13
Modulus of elasticity (E_b II), GPa	14.5–16.5	7.3–11.0–21.4	10.0–16.0–18.0	10.0–11.7–13.2
Shock resistance (*a*), kJ/m^2	45–100–130	10–46–110	30–100–190	10–60–160
Brinell-hardness (HB I), MPa	22–49	12	34	34
Chemical properties				
Normal wood				
Lignin, %	19.3–27.4	19.0–29.0	11.6–22.7	24.9–34.3
Cellullose, %	45.3–56.5	38.1–46.0	33.7–46.4	37.6–42.8
Pentosans, %	23.6–27.1	6.8–12.0	17.8–25.5	19.0–25.5
Extractives, % (Ollinmaa 1955)	2.70–3.09			
pH-value	ca. 4.8	4.0–5.3	5.1–5.4	3.9
Reaction wood				
Lignin, % (Ollinmaa 1955)	16.2–19.7			
Cellulose, % (Ollinmaa 1955)	55.6–60.4			
Extractives, % (Ollinmaa 1955)	1.25–2.53			

Spruce and oak: 1 early wood, 2 late wood, 3 thin growth rings, 4 broad growth rings, 5 small rays, 6 large rays