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Timo Kärki

JOENSUU RESEARCH STATION

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GREY ALDER (*Alnus incana*) AS A RAW MATERIAL FOR MECHANICAL WOOD PROCESSING IN FINLAND

Timo Kärki

ACADEMIC DISSERTATION

To be presented with the permission of the Faculty of Forestry of the University of Joensuu, for public criticism in Auditorium C2 of the University, Yliopistokatu 2, Joensuu, on April 14, at 12 o'clock noon.

JOENSUUN TUTKIMUSASEMA
2000

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ABSTRACT

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In the Savo-Karelia area, the attitudes of sawmillers towards using grey alder as raw material were found to be positive. It was also determined in Study II, with regard to tree species that 10 % of all furniture in Central European markets was made of alder. This means that alder was the fourth most popular tree species for furniture after pine, beech and spruce.

The construction of different quality models indicated that in grey alder stands there is much unexplained variation. In the case of the tree height model, tree diameter was the strongest explanatory variable. The model concerning height to the lowest living branch showed similar results. In the case of the lowest dead branch, only the height to the first living branch could be used as a predictor. In all height models, the largest variation was the residual variation between trees in a plot. The technical quality of grey alder logs and sawn timber varies considerably. Grey alder stems have knots from the butt to the crown, and the length of the knot-free section at the butt is short. The boundary between a dry-knot section and a fresh-knot section is not as obvious as, for example, with softwoods.

There have not previously been volume tables for grey alder, so the volume table for birch with bark was chosen as a point of comparison for the whole tree-volume table. It was concluded that, for extreme sizes of grey alder stems, the volume estimates for grey alder differ 10-11 % from the estimates calculated with the volume tables of birch.

The theoretically calculated stumpage price for grey alder logs was 158 FIM/m³. This result is a computational price that is based on average estimates. However, this price gives an indication of the price level suitable for grey alder logs in Finland. It was also shown in the furniture manufacturing calculation that the raw-material price for alder is not yet the limiting factor. The price limit for good quality alder sawn timber could be 3 000 FIM/m³.

Keywords: *Alnus incana*, grading, value, quality classification, forest product markets.

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Esipuhe

Kiinnostukseni lepän tutkimukseen alkoi vuosina 1993-94, kun kiersin puuta jalostavien yrittäjien luona Savo-Karjalassa keräämässä aineistoa pro gradu – työtäni varten. Tällöin selvisi yrittäjien ilmeinen mielenkiinto harmaaleppään raaka-aineena, mutta keskusteluissa tuotiin usein ilmi esteet näiden puulajien käytön kehittämiselle: sahauksen ja kuivauksen ongelmat, puun laadun ennustettavuuden ongelmat sekä laatu- ja mittakriteerien puute. Lisäksi lepän markkinointia haluttiin kehittää, sillä yrittäjien tuntemuksien mukaan paikallisia markkinoita oli, mutta mikä oli käyttö muualla, suuressa maailmassa ? Mihin leppää yleensä käytetään ?

Tällöin hahmottui mielessäni kokonaisuus, jossa lähdettäisiin esimerkiksi huonekaluteollisuuden vaatimuksia hyväksikäyttäen etenemään kohti tuotannon alkupäätä eli metsää tavoitteena laskea näin lepän sahauksen kannattavuus. Haasteelliseksi tehtävän teki väite siitä, että suomalaisista lepikoista ei ole muuhun käyttötarkoitukseen kuin hellapuuksi, useimpien mielestä ei siihenkään. Lisäksi kuulin usein mielipiteitä, että leppä on kansainvälisestikin katsottuna ”nolla” puulaji, jolla ei ole arvoa taloudellisesti katsottuna muuallakaan maailmassa.

Näillä perusteilla ja ajatuksilla aloin aktiivisesti hakea syksyllä 1995 rahoitusta tutkimukseni aloittamiseksi. Sain työhöni henkistä sekä ideallista tukea professori Pertti Harstelalta, jota tahdon tässä yhteydessä erityisesti kiittää luovasta sekä idearikkaasta ohjaustyöstä tutkimuksen aikana. Lisäksi tahdon kiittää professori Erkki Verkasaloa, joka on valaissut minulle lehtipuututkimuksen metodologiaa sekä professori Matti Kärkkäistä, joka oli ideoimassa varsinkin markkinatutkimusta. Edellä mainittujen lisäksi tahdon kiittää niitä lukuisia henkilöitä, jotka ovat edesauttaneet väitöskirjani syntymistä. Taloudellisesti työtäni ovat tukeneet Joensuun yliopisto, Suomen Kulttuurirahasto, Suomen Akatemia, Maa- ja metsätalousministeriö, Metsämiesten Säätiö sekä Metsätieteellinen Seura. Rahoittajille parhaat kiitokset.

Joensuussa helmikuun kirkkaina talvipäivinä vuonna 2000

Timo Kärki

CONTENTS

ORIGINAL PAPERS I - V

LIST OF ORIGINAL PAPERS

This dissertation is a summary of the following papers, which are referred to in the text by Roman numerals I - V.

I Kärki, T. 1997. Sahauskelpoisen erikoispuun laatuvaatimukset ja käyttö Savo-Karjalan alueella. Folia Forestalia 1/1997: 37-48.

II Kärki, T. 1999. Species, furniture type, and market factors influencing furniture sales in southern Germany. Accepted to Forest Products Journal 12th January 2000. Will be published in Volume 50 (4). 14 p.

III Kärki, T., Maltamo, M. & Eerikäinen, K. 1999. Diameter distribution, stem volume and stem quality models for grey alder (*Alnus incana*) in eastern Finland. Accepted to New Forests 7th December 1999. In print. 22 p.

IV Kärki, T. 1999. Predicting the value of grey alder logs (*Alnus incana*) based on external quality. Silva Fennica 33(1): 13-23.

V Kärki, T., Eerikäinen, K., Heinonen, J. & Korhonen, K.T. 1999. Harmaalepän (*Alnus incana*) tilavuustaulukot. Folia Forestalia 1/1999: 39-49.

NB: These articles should be referred to according to the bibliographic information given above. No reference should be made to the reprint in this thesis.

The author is responsible for the following in the joint papers:
In papers III and V the author was having main responsibility in planning of the sampling, measuring and analysing, and writing the results.

1 INTRODUCTION

Improved use of grey alder has been under discussion in Finland for the past 10-15 years. Recently, there has been further interest in using grey alder as raw material for the mechanical wood industry. The fact is that the potential of hardwoods will increase in future; for example, Siitonen (1990) calculated that in 1999-2019 the harvesting possibilities for hardwoods (excluding birch) will be doubled because of the increased growth and volume of hardwoods. In these calculations the effects of changes in silviculture (biodiversity and preferring hardwoods) are not considered.

Although the matter has interested many people and institutions, the „case of grey alder“ has been little studied. In Finland, research on grey alder began in the 1930´s with a review of its utilization for mechanical processing as well as for pulping and papermaking (Routala & Sihtola 1934). The fibre-morphological and pulping characteristics of grey alder were studied by Bruun & Slungaard (1957) and Alestalo & Hentola (1967). The results showed that, compared with other Finnish tree species, grey alder is short-fibred. Compared with birch, sulphate pulps of grey alder have a short beating time and good tension and bursting strength, but poorer tearing strength. Other technical properties such as basic density, proportion of bark and dry matter content of grey alder were studied by Lehtonen et al. (1978), Mali (1980), Farmer (1981) and Björklund & Ferm (1982). The wood of alder is homogeneous and easy to work, making it suitable for various useful objects and many special purposes, e.g. making music instruments (Salmi 1977 and Kärki 1997). The yield of grey alder has been studied by Miettinen (1933) and Mäkinen (1984). Saarsalmi et al. (1985, 1991, 1992) studied the biomass production of grey alder in short rotations and found that growth of young grey alder is better than that of pine, spruce, birch or aspen. However, the growth of grey alder begins to slow down and the occurrence of decay increases at the age of 25-30 years (Miettinen 1933, Tikka 1954, Ilvessalo & Ilvessalo 1975 and Vuokila 1977). The profitability of growing grey alder depends on its suitability as a raw material for industry.

Even though the possibilities and markets for grey alder timber have been studied so little, a literature review is presented in chapters 2.1 – 2.5 in order to give an idea of the wood procurement, use, processing and markets of grey alder. The wood procurement is reviewed by studying new possible trade forms, timber exchange and terminal trade, use and processing by looking into the current state of the use of alder timber in Finland and markets by clarifying the potential markets for grey alder timber in Germany, which is the most important export market for products of the Finnish mechanical forest industry.

2 WOOD PROCUREMENT, PROCESSING AND MARKETS FOR GREY ALDER – A LITERATURE REVIEW

2.1 Alder in Finland

In Finland, grey alder is considered a special tree species and the timber of grey alder as special timber. Both definitions are also used in this dissertation. According to Kärki (1995), special tree species can be defined as species which either grow outside their natural area of distribution or cover a small proportion of the forest land / annual growth or are different in structure and character from the main species growing in a particular area. Special timber is defined as timber that has a particular end-use or dimensions or is little used.

Alder is distributed throughout Finland, with the exception of the northeasternmost part of the country. There are two alder species, grey alder (*Alnus incana*) and black alder (*Alnus glutinosa*). Grey alder can often be found in eastern Finland on formerly cultivated land, to which grey alder as a rapidly growing pioneer tree species has spread. The proportion of grey alder of the total number of trees is considerable; but in terms of stand management, grey alder has been cut down and the volume of grey alder compared to the number of stems is marginal (Figures 2 and 3). Black alder grows mainly in southern Finland as naturally regenerated and planted forests (Holmåsen 1991) and is typically a species for wet biotope-sites like shore forests, although grey alder prefers dryer areas than black alder does. Alder species are known as tree species that improve the quality of soil (Huss-Danell & Lundmark 1987).

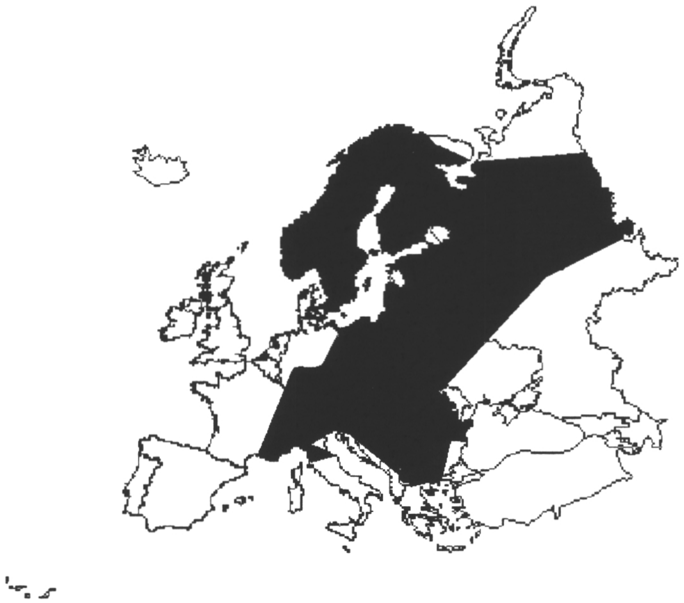

Figure 1. Natural area of distribution for grey alder in Europe (Holmåsen 1991).

Grey alder, which typically occurs in semiboreal and boreal forests, has spread out further northward to the limit of forest growth than black alder has. From Finland the area of distribution for grey alder continues to eastward the forest zone of Russia, to the Caucasus Mountains, Siberia, the Kamtchatka peninsula and Japan. From Finland southward, grey alder can be found in much of Central Europe with the exception of Britain, Denmark, northern Germany, Holland, Belgium, western France, the Pyrenean peninsula and the southern part of the Balkan peninsula. Familiar forms of grey alder can also be found in the northern part of North America. (Holmåsen 1991)

The proportions of aspen, black alder and grey alder in terms of stem number and volume in southern Finland (15 southest Forestry board districts) are shown in Figures 2 and 3. In order to compare the proportions of different potential special tree species in Finland, the proportions of aspen are also shown. These figures are based on the results of the Eighth National Forest Inventory (VMI8).

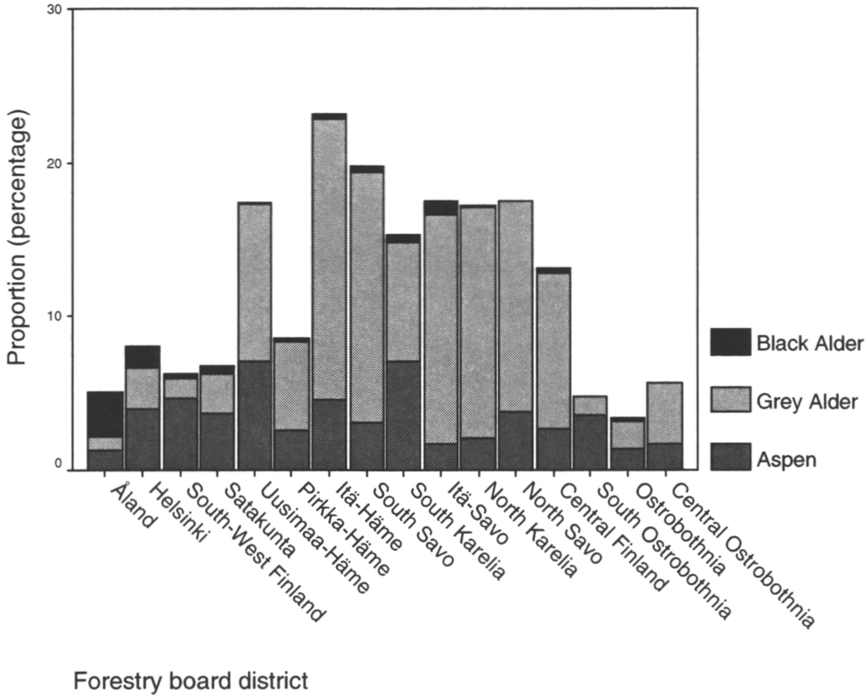

Figure 2. Proportions of aspen, black alder and grey alder based on stem number in southern Finland.

On the basis of stem number, the proportion of alder and aspen is greatest in Itä-Häme (23.1 percent). The proportion of grey alder is largest in the forest districts of Itä-Häme, South Savo, Itä-Savo, North Karelia and North Savo. On average, in Southern Finland the proportion of grey alder according to stem number, is 9.6 percent. Black alder occurs in low proportions; in Åland, Helsinki and Itä-Savo, however, the proportion is over 1 percent.

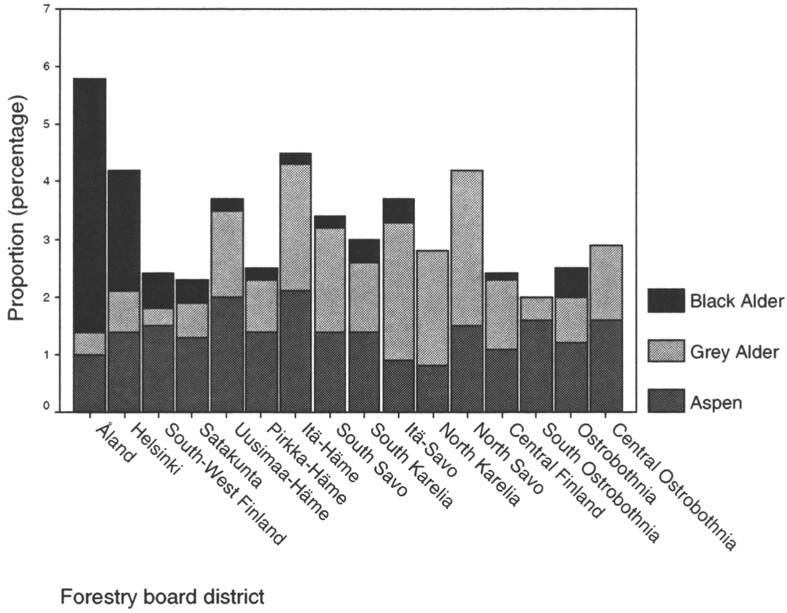

Figure 3. Proportion of aspen, black alder and grey alder of the total tree volume in southern Finland.

The proportion of aspen, grey and black alder calculated on the basis of tree volume is greatest in Åland (5.8 %) (Figure 3). The next three are quite equal, Itä-Häme (4.5 %), North Savo (4.2 %) and Helsinki (4.2%). In the provinces of Åland and Helsinki, the proportion of black alder is the greatest; in the other districts aspen and grey alder dominate.

In conclusion, it can be said that the proportion of grey alder, determined according to both stem number and basal area, is greatest on former burnt-over areas in eastern Finland. When total volume is considered, the amount of grey alder is spread out evenly throughout southern Finland.

2.2 Physical and mechanical properties of alder timber

There are three common alder species in the world, all of which are widely used in mechanical wood processing. As mentioned previously, grey and black alder grow in Finland, while red alder (*Alnus rubra*) is wide-spread in North America. Despite the fact that there are three different species of alder, alder timber is commonly sold as one species. In Table 1, the most important physical and mechanical properties for mechanical wood processing of different alder species are compared. Cherry is used as a comparison tree species, while alder is frequently mentioned as substitute for cherry in furniture manufacturing (Grosser 1985 and Kohonen 1997).

Table 1. Physical and mechanical properties of grey alder, black alder, red alder and cherry (Hakkila 1970, Salmi 1977, Farmer 1981, Björklund & Ferm 1982, Grönros et al. 1995 and Wagenführ 1996).

Characteristics	Grey alder *Alnus incana*	Black alder *Alnus glutinosa*	Red alder *Alnus rubra*	Cherry *Prunus serotina*
Physical properties				
Density (kg/m^3)				
- oven-dry	361	490	430	530
- dry-air dry	430	530	460	580
- green	600	850	737	900
Shrinkage (%)				
- longitudinal	0.35	0.35	-	0.2
- radial	4.5	4.0	4.0	4.0
- tangential	9.5	9.7	7.0	7.0
- volumetric	14.1	14.2	12.6	11.5
Mechanical properties				
Bending strength (MPa/m^2)	88.3	83.4	44.6	54.9
Compression strength (MPa/m^2)	44.1	39.2	20.3	24.3
Hardness (HJ $\perp$, N/mm^2)	43	43	20	29
Tensile strength (MPa/m^2)	-	-	2.6	3.9
Shearing strength (MPa/m^2)	4.9	4.4	5.3	7.7

When the physical properties of alder species are compared, grey alder is the lightest of the three alder species, and shrinkage is also greatest in grey alder, followed closely by black alder. On the other hand, the mechanical properties of grey alder seem to be noticeably better than those for red alder. The mechanical properties of black alder are virtually the same as for grey alder, and it is mentioned in some references that they behave equally in finishing (Salmi 1977, Mali

1980 and Grönros 1995). The wood of grey alder is reddish white and slightly lighter than that of black alder. Sapwood and heartwood are usually indistinguishable, as is also true for black alder. According to Mali (1980) and Grönros et al. (1995), the behaviour of grey alder wood e.g. in drying, machining and finishing is easy to control.

The wood of freshly felled black alder is reported to have a warm light brown colour, which changes rapidly to deep bright orange. The colour of the processed wood gradually fades to dull nut brown. The wood of black alder is reported to dry well and fairly rapidly, and degradation during seasoning is minimal. Bending strength and resistance to shock loads are reported to be low, and stiffness is rated as very low. The timber of *Alnus glutinosa* is very difficult to distinguish from that of *Alnus incana* (Laidlaw 1960 and Farmer 1981).

The heartwood of red alder, which is indistinct from the sapwood, is whitish when freshly cut but upon exposure to light changes to reddish-brown. Red alder has been described as "pleasing" in appearance, with grain that is typically straight and subdued. Although the colour has often been described as delicate, the wood lacks any outstanding figure. The wood is reported to be easy to dry, and seasons fairly rapidly with little degradation. Specially developed kiln schedules, careful handling of logs and freshly milled sawn timber are reported to be essential for obtaining and maintaining uniformity of colour during drying. Varying coloration ranging from yellow to deep red, sometimes mottled, is caused by oxidation of the extractives present in the wood. The bending strength of the species is considered to be medium, being much weaker than white oak or teak in air-dry condition (about 12 percent moisture content). Red alder timber is not hard and can be dented and marred easily. Therefore, it is not recommended for uses that require strength. (Kline 1987, USDA 1987 and Niemiec et al. 1995)

2.3 Wood procurement of alder timber

Wood procurement of grey alder nowadays is mainly as standing sale, sale at delivered price or cash transaction. There has been an interest in developing new business forums, like timber exchange and terminal trade, for trading of grey alder timber. The first models for timber exchange have been provincial exchanges (run by forest societies associations and the Finnish Forest Research Institute), so-called information services, to which the person who wants to sell special timber announces the timber for sale and from which the buyer can for a small fee buy information about timber for sale. The trade and price are negotiated directly between seller and buyer. One new procurement possibility is wood procurement by a forest service enterpriser, in which an independent enterpriser buys the wood himself or sells timber directly to client and himself takes care of the logging and transport.

The idea of a timber exchange is quite simple. The sellers and buyers in stock give their offers to an exchange system through the internet where the trades are made according to certain rules. In order to work properly, there must be enough sellers and buyers in the exchange. The problem in establishing a timber exchange is that there are no recognized quality and dimension classifications that could be used for special timber. It has also been unclear how to take into account in the price the time of delivery and terms of payment. The level of logging and transport costs has also been unclear. According to Kallio & Salo (1992), there are two possible forms for timber exchange: automatic exchange and real-time exchange. The trades are decided in the automatic exchange according to bids that have been announced by a certain time and the trades are then made immediately. The real-time exchange works differently; these trades are made after the exchange period so that all interested parties can make trades as if they were at an auction (Kuula et al. 1992).

The partners in timber exchange can be forest owners, firms or even independent forest-service enterprisers. Organisations that might run timber exchanges could be, for example, stock exchanges, trading houses, service companies or separate joint enterprises (Vepsäläinen & Kuula 1992). According to this idea, individual sellers could transact business through different advisors (like forestry associations).

Another new possibility for trading grey alder timber is terminal trade. The typical problem in trading grey alder timber is that the quantities of timber for sale are small. In this case, there is a need to collect the small amounts together many times in order to obtain larger trade amounts if there are no suitable road-side landings to which small amounts can be transported to wait for long-distance transport. According to Siikaluoma (1991), terminal trade means sale at delivery in which the timber quantities are measured and/or accepted at so-called ”village terminals”. Terminal sites could be areas that have no other particular use, like former gravel pits. Terminal trade could also be practised at sawmills.

In terminal trade, timber is delivered from roadside landings to terminals with tractors or lorries by timber sellers or buyers. This kind of trades are, according to Siikaluoma, unprofitable unless the transport from forest to terminal is short and the quantities very large. Investment in expensive forest equipment is seen as a hindrance to profitability. On the other hand, Siikaluoma (1991) sees the possibilities of terminal trade in trading special timber. Cost gains could be reached in the first place in actual measuring and in changeovers from one stock to another. This principle is well adapted to special timber measurement, while part of the timber is rarely measured or can be measured with the measuring equipment on a harvester (Mäkelä 1986).

Kärki (1995) calculated the wood procurement costs for timber assortments of grey alder with a spreadsheet calculation of Metsäteho (Oijala et al. 1994). The average wood procurement costs for grey alder logs were calculated to be 99.85 FIM/m^3 and for grey alder pulpwood 142.76 FIM/m^3. The calculation was made for a spruce thinning where grey alder timber was supposed to grow and be harvested after 30 years (manual felling, transport and administrative costs included). On average, the wood procurement costs from a thinning (logs and pulpwood) with manual felling and transport were 114,70 FIM/m^3 (Oijala 1994), so the wood procurement of grey alder logs was 15 FIM/m^3 cheaper and wood procurement of grey alder pulpwood 43 FIM/m³ more expensive than for thinnings on average according to the example calculation. Kärki (1995) also calculated the procurement costs in a situation where grey alder would grow as a pure stand for final felling. In this case, the wood procurement costs were considerably smaller, being then equivalent to birch.

2.4 Markets for alder timber

The use of alder (*Alnus glutinosa* and *A. incana*) has increased rapidly in the past few years, among other things, in sauna-furnishing and manufacturing panels. Alder is also used in furniture, utility articles, ornaments and in the cellulose and fibreboard industry (Salmi 1978a,b) In the furniture industry alder is much utilized as a competitive alternative to walnut, cherry and mahogany (Grosser 1989). Grey and black alder are used for the same type of end-products.

The amount of grey alder timber in the Finnish markets seems to be limited (Table 2). The special trees used most in Finland are aspen, alder, larch and curly birch. The amounts of other domestic hardwoods like oak are marginal. At the same time, in 1993 35 000 m³ of hardwood timber (excluding birch) was imported to Finland. (Louna & Valkonen 1995).

Table 2. Use of domestic special timber in Finland in 1995. Use as firewood is excluded. (Verkasalo 1993, Louna & Valkonen 1995, Kärki 1995, Hynynen & Viherä-Aarnio 1999)

Tree species	Used amount
Aspen	Logs: 10 000 - 15 000 m³ Pulpwood: 150 000 – 200 000 m³
Alder	Logs: 20 000 m³ Pulpwood: 30 000 m³
Curly birch	Some hundred kilos
Larch	1 000 - 2 000 m³
Oak	100 m³
Mountain ash	< 100 m³
Maple	< 100 m³
Linden	< 100 m³
Ash	< 100 m³
Elm	< 100 m³

It must be noted that the estimates of Louna & Valkonen (1995) for alder were calculated by using data in which only the larger firms (over 20 employees) were represented; from the smaller firms there was only a 10 % sample. This indicates that the importance of smaller firms is underestimated. A more realistic estimate for the use of grey alder in mechanical wood processing could be about 50 000 m³ per year. This rough estimate is based on the supposition that most alder timber is processed mechanically by small saw mills as a supplement to softwood processing.

Alder is counted as one of the „trend tree species“ in the German markets, which are the most important export markets for the products of Finnish mechanical forest industries. In German markets, the use of alder timber has increased rapidly during the last five years. In these markets, some domestic grey and black alder timber is also available, but most of the alder timber is imported from the United States and eastern and southern Europe. Import of alder from eastern Europe has increased significantly in the last few years. The import from these countries is very competitive in price, and most of this timber is imported directly to the processers, bypassing the timber importers (Kräftiger Anstieg ... 1998). However, in this study the import of hardwoods to Germany is examined only through import from the largest exporting country, the United States, because accurate statistics on the import of alder from eastern and southern Europe are not available. The import of hardwood timber to Germany from the United States, divided into tree species and sortiments, in 1997 is presented in Table 3.

Table 3. Import of hardwood timber to Germany from the United States divided into tree species and sortiments in 1997 (values in mill. FIM). (Handelsstrukturen für … 1998)

Tree species	Round timber	Sawn timber	Veneers	Total	Proportion (%)
Ash	11.34	11.34	15.99	38.67	3
Birch	-	2.65	1.62	4.27	0
Cherry	69.71	6.37	63.99	140.07	12
Walnut (hickory & pecan)	-	1.13	-	1.13	0
Maple	9.45	62.10	39.20	110.75	9
Red oak	5.02	3.35	59.51	67.88	6
Walnut	1.40	2.97	44.01	48.38	4
Red alder	**0.97**	**335.88**	**-**	**336.85**	**28**
White oak	-	139.86	123.12	262.98	22
Yellow poplar	1.35	6.59	-	7.94	1
Other	19.44	16.69	162.65	198.78	16
Total	118.68	588.93	510.09	1217.7	100

When different hardwood species are considered, the proportion of imported alder is greatest (28 %). After alder, the proportions of imported white oak (22 %) and cherry (12 %) are next and the group „other species“ makes up 16 % of the import of hardwoods. It is interesting that alder imported from the United States is almost all sawn timber while, e.g. for white oak, the proportion sawn timber / veneers is equal in value. Cherry is imported mostly as round timber and veneers, but small amounts of sawn timber are also imported. It seems that cherry is imported as unprocessed round timber and alder as slightly processed sawn timber; there is a possibility that cherry is sawn or manufactured into veneer, whereas alder is used as sawn timber for furniture and veneered by slicing. Not all alder is used for the furniture industry; it is also used for other end-products such as parquet. The import of hardwood timber from the United States to the countries of the European Union in 1996 and 1997 is presented in Figure 4.

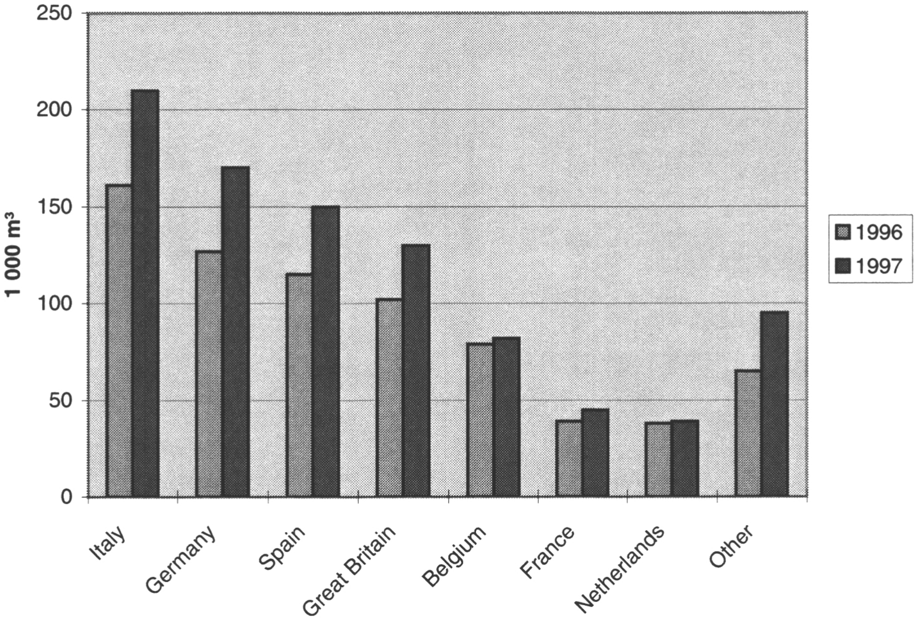

Figure 4. Import of hardwood sawn timber to the countries of the European Union from the United States in 1996 and 1997. (Handelsstrukturen für … 1998)

According to Figure 4, the import of hardwood timber to the European Union from the United States has increased in all countries from 1996 to 1997, also to the group which comprises the other members of the European Union, including Finland. In the case of Germany and Italy, the import has increased above all due to the increased import of alder (Handelsstrukturen... 1998).

There are no statistics available concerning the price of alder sawn timber per cubic meter imported to Germany from the United States, but a rough estimate (EXW delivery conditions, ex works) can be calculated using the information in Table 3 and Figure 4. From Table 3 we can see that of all hardwood sawn timber the value of alder sawn timber imported to Germany from the States is 57 %, the value of white oak 24 % and the value of maple 11 %. These three most important species comprise 92 % (538 mill. FIM) of the whole value. The value of imported hardwood sawn timber (588.93 mill. FIM) divided by the number of imported cubic metres (170 000 m^3) gives about 3 500 FIM / m^3. It can be said, according to tree species, that the average price per cubic metre for oak and maple is higher than that for alder. If we suppose that this is so, the average price per cubic metre for imported alder sawn timber is about 3 000 FIM / m^3. In 1996, the average price per cubic metre for beech imported to Finland from Germany was 3 500 FIM / m^3, which can be used as a reference price for alder (Außenhandel nach ... 1997). Other interesting reference prices for sawn timber are the import prices for hardwood and softwood imports to Germany from Finland in 1996: spruce 990 FIM / m^3, pine 1 790 FIM / m^3 and birch 2 470 FIM / m^3. The latter prices are delivered at frontier (DAF) prices, so, to be able to compare the cubic prices with the other before mentioned (Außenhandel nach ... 1997), we have to add some hundred FIM to the price of the alder sawn timber.

The value of hardwood veneers imported to the countries of the European Union from the United States in 1996 and 1997 is presented in Figure 5.

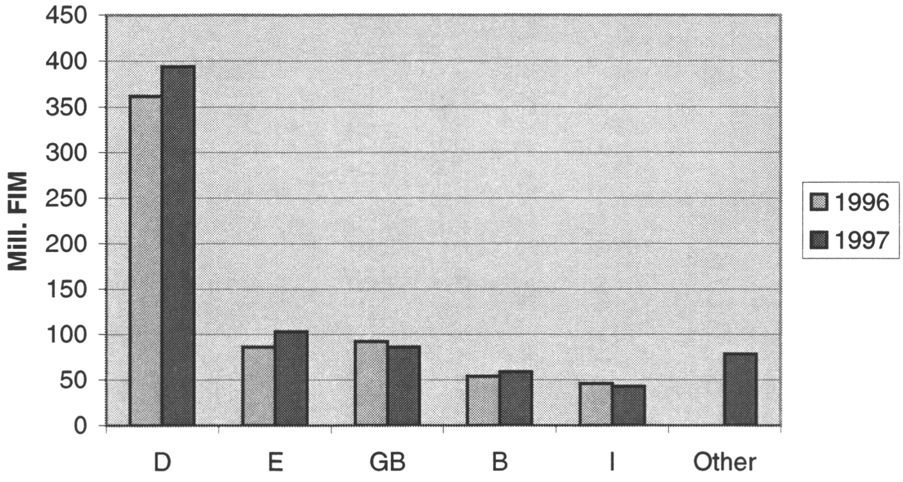

Figure 5. Value of hardwood veneers imported to the European Union from the United States in 1996 and 1997. The values are in FIM according to EXW conditions. (Kräftiger Anstieg ... 1998)

During 1996 and 1997, the import of veneers to Germany and Spain from the United States increased slightly, but the import to the United Kingdom decreased slightly. As seen in Table 3, according to value, the veneers are mainly white oak and cherry; the proportion of imported alder veneers is marginal. The prices for hardwood logs in German markets are presented in Figure 6.

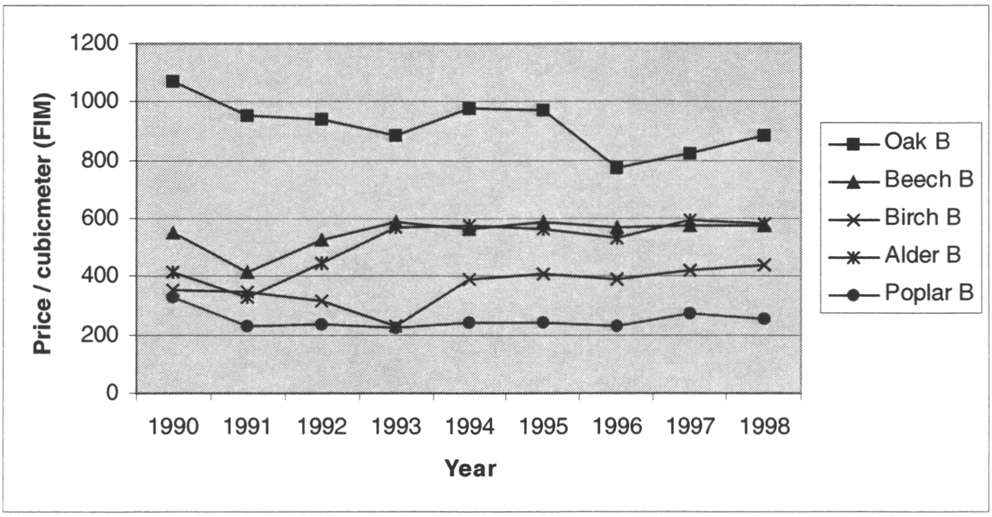

Figure 6. Hardwood log prices (B-quality) in the State Forests of Baden-Württemberg and Bayern 1990-98. (Jahresberichte der Baden-Württembergische und Bayerische Staatsforsten 1991-1998).

The price of alder, including both black and grey alder, has been increasing slightly in the last seven years, and the price is fixed to about 600 FIM/m³. The price of alder has followed that of beech very closely and was 20-30 % higher than the price of birch.

2.5 Profitability of sawmilling and furniture manufacturing

No studies are available concerning the profitability of sawmilling and furniture manufacturing from grey alder timber. There are, however, some studies which can be used as a basis for calculating the value of grey alder for mechanical wood processing (Chapter 5.4). Kuukka (1980), Lönnberg & Vesikallio (1980), Ryti (1987), Heino (1988a, b) and Pöyhönen (1991) investigated the profitability of sawing and processing of softwoods. Kuukka (1980), Heino (1988a,b) and Pöyhönen (1991) studied the profitability of individual sawmills. Heino (1988a) came to the conclusion that the smaller the sawmill capacity, the more profitable the sawmill was. However, the range of annual production was as narrow as 40-50 000 m³ to 100-110 000 m³. Moreover, the change in the natural distribution area of tree species reduces the profitability of sawmilling. This is due to the rising costs of wood procurement. Heino's conclusion that the relationship between yield and grade had no effect on profitability is also interesting. As a major conclusion, he proposes some possible business strategies. One of them is a strategy where the sawmill

- specializes in special wares
- invests in marketing
- invests in developed controlling system
- invests in "flexible" equipment
- controls the manufacturing process from the forest to the markets.

The average cost structure of the Finnish sawmills in 1975-85 was also presented by Heino (1988a). Of the total costs, the proportion of raw material was 68 %, labour 13 %, energy 3 %, maintenance 3 %, other variable costs 9 % and capital costs 12 %. According to these figures, the average deficit was 7 %. It was also found that the relative proportion of energy and maintenance from the total costs increased as the capacity of the sawmill grew.

Heino (1988b) compared the profitability of sawmills and wood processing. In his report he mentions that the accuracy of bookkeeping at sawmills, if any, is poor. The raw material costs were 50-70 % (average 58 %) of the total costs at the sawmill. The productivity of capital was poor, even negative at sawmills, whereas the profit rate was 3.1% at the further processing mills. As a conclusion, there was a need to specialize in a particular product. Accordingly, no mill needs to make all types of products, but sawmillers should invest in individual sawing strategy, taking into account the raw material resources of the area, the competition and the market conditions.

3 AIM OF THE STUDY

According to the literature reviewed, mechanical processing of grey alder has been studied very little. No studies are available, e.g. on the timber quality and stem volumes of grey alder. The main aim of this dissertation was to investigate the suitability of grey alder for mechanical wood processing in Finland. The aim divides into following subaims:

i) evaluating the markets for grey alder in Finland and Germany
ii) evaluating the tree and saw log quality of natural born grey alder forests in Finland
iii) calculating the volume and quality functions for grey alder logs
iv) calculating the processing value for grey alder timber based on the articles presented in this dissertation

4 MATERIAL AND METHODS

The materials and methods of the various studies (I – V) are presented in more detail in each article. Therefore in this chapter the material and methods are outlined only generally. Four different sets of data were used in this study. In Study I, the empirical material was collected with a postal inquiry from firms that processed wood mechanically in the Savo-Karelia area. In Study II, the method used was an advertisement study. The material in that study consists of advertisements collected in southern Germany in the economic area of Munich. The data were collected from advertisements published in provincial and local newspapers and from the advertisements of furniture stores. Both of these first studies are descriptive, partly social research that charts the situation in practise.

The materials in Studies III and V included 33 stands situated in the provinces of Northern Karelia and Northern Savo in eastern Finland. The stands were naturally regenerated, but at least part of them were managed. The material is measured data and thus differs considerably from the material in Studies I and II. The research material in Study IV comprised 229 grey alder saw logs from two pure stands of grey alder, both situated in Northern Savo, one in Maaninka and the other in Nilsiä. The trees were selected randomly, with the only limitation being that the logs had to be sawable (stem form).

The methods used and reported in different articles are quite heterogeneous. The methods used and their influence on calculation of the processing value are shown in Table 4.

Table 4. Methods used in the articles and the relevance for the calculation of the processing value.

Article	Method	Used in the calculation
Article I		
	Principal component analysis Cross-tabulation	-
Article II		
	Cross-tabulation	Price level for the end products
Article III		
	Weibull distribution, maximum likelihood estimation Regression analysis Logistic regression analysis Cross-tabulation	Simulation of the example forest
Article IV		
	Regression analysis Cross-tabulation	Sawn timber yield, grade distribution of saw logs and sawn timber
Article V		
	Regression analysis Cross-tabulation	Simulation of the example forest

Different types of regression analysis were used in three articles. Cross tabulation was used in all five articles, and it was the only method in Article II. In Article II, a Chi-Square Test was also attempted, but no significant differences were found. Thus, the test was omitted from the article. The main ideas of different methods, like principal component analysis and regression analysis, are clarified in each article, so the different methods are not presented in detail here.

Article I was the beginning of for the whole dissertation. It was found in Study I, that grey alder was the most interesting special tree species and should be investigated as a raw material for mechanical wood processing. The reason for this variable group of articles that includes aspects of marketing research, forest mensuration and wood technology is that there were no real studies that could be used as a basis for calculation of the processing value. Volume models were lacking, as well as information about the saw log and sawn timber quality of grey alder.

The possible processing value for grey alder timber is estimated with a theoretical calculation (Chapter 5.4). The information from Articles II, III, IV and V is used in different stages of the calculation as follows:

1. The structure of the example forest was calculated by using the diameter distribution, height and volume models from Articles III and V.

2. The quality criteria and volume tables from Articles IV and V were used in estimating the saw log and industrial tree volumes.
3. The costs of logging and transport were calculated using the information presented by Oijala (1994), Huotari (1995) and Kärki (1995).
4. The grades and values of the logs / sawn timber were estimated using the information in Article IV.
5. The costs of sawmilling were calculated based on Heino (1988a) and Pöyhönen (1991).
6. The costs of furniture manufacturing were calculated based on Lahti (1991), Aravuo (1994), Juva & Ahtorinne (1995) and Huonekalujen valmistus (1996).
7. The log stumpage prices and sawn timber prices were calculated according to the information given above. Saw log and sawn timber prices were compared with the statistics reviewed here and in other studies.

5 RESULTS

5.1 Markets for alder timber (I, II)

In Study I, the current quality and dimension criteria for grey alder used by the sawmillers in eastern Finland and the current state of the use of grey alder was investigated. The sawmillers limited the minimum top-diameter criteria for grey alder logs to 13 cm, but they also wanted to use smaller dimensioned grey alder logs if the stem form was suitable for sawmilling (Table 6; I). The minimum length for grey alder logs was set at 2.5 m (Table 7; I). A little decay was allowed, and sound knots were accepted by half of the sawmillers.

In the Savo-Karelia area, the attitudes of the sawmillers towards using grey alder as a raw material were found to be positive. The tree species of the greatest interest was grey alder. According to Study I, the interest in mechanical processing of special timber is strong; 70 % of the responding companies were interested in extending their wood processing to special tree species. The wood used by the companies studied was obtained as their own procurement or directly from forest owners. The sawmillers wanted to develop wood procurement on this basis also in future. Of the sawmillers (12 %), were interested in developing their wood procurement through timber exchange and 28 % through any system that would work effectively.

A principal component analysis was also made in order to study factors affecting the willingness of the enterprisers to use grey alder as a raw material for mechanical wood processing (Table 9; I). Five factors were built in analysis, of which one describes the behaviour of the whole population of sawmillers studied and four of which can be described *as new production possibility, wood procurement, markets* and *development projects*. Part of the enterprisers thought that mechanical processing of grey alder is a *new production possibility*. This could mean that processing grey alder was considered to be a balancer and diversifier of the production as the economic trends vary. *Wood procurement* of grey alder was considered to be a problem when mechanical processing of grey alder was started or increased. The reasons for this are uncertainty about suitable quality and dimension criteria and the unstable level of the stumpage price for grey alder. An important component in the analysis was *markets* for grey alder timber. According to the questionnaire results, customers had ordered alder or aspen timber from every third enterpriser and some of them could not meet the demand. The fourth component in the principal component analysis was *development projects*, which indicates that enterprisers are interested in and also need training, counselling and consultation concerning grey alder.

The aim of the Study II was to investigate the furniture markets in Central Europe as a case study, focusing on the economic area of Munich, to determine how these markets are divided according to tree species, furniture type and argumentation used in furniture marketing, i.e. how the products are sold. A further aim was to ascertain how much alder timber is used in the furniture business. According to the results of this study, 10 % of all wooden furniture was made of alder. This means that alder was the fourth most popular tree species after pine, beech and spruce (Table 2; II). The proportion of alder furniture was even higher (15 %) for plate-structured furniture, 10 % for partly solid-structured furniture and 5 % for solid-structured furniture. Softwood furniture from pine and spruce was sold as solid-structured (Table 5; II). In plate-structured furniture, in particular, the proportions of these species were marginal. All tropical hardwood furniture of teak, mahogany and acacia was solid-structured. Alder and oak made up equal proportions of every structural type of furniture (solid-structured, partly solid- and plate-structured), but beech furniture was mostly plate-structured and only occasionally solid-structured. On the whole, oak furniture was the most expensive, with alder following as a close second. Furniture from beech was noticeably less expensive when used as partly solid but significantly more expensive as plate-structured. Pine and spruce furniture was the least expensive when it was solid and partly solid-structured. Plate-structured maple and beech furniture was considerably more expensive than that made from alder or oak.

5.2 Tree and log quality of grey alder (III, IV)

In Study III, different models were constructed for tree and stand characteristics of grey alder. These models included models for diameter distribution, tree height, height to the first living and dead branches, taper curve and occurrence of rot. The models constructed can be applied in two different situations: tree diameters are either measured or not.

Parameter models of fitted basal area diameter distributions of the Weibull distributions are presented in Table 4 (III). Median diameter was used as explanatory variable for both parameters. Constructed models are very simple including only one explanatory variable. The degree of determination is high for parameter b but quite low in the case of parameter c. This result is similar to some previous studies concerning Weibull distribution (e.g. Rennolls et al. 1985, Maltamo 1997).

The predicted diameter distributions using parameter models (Table 4; IV) were validated using χ^2-statistics. The validation indicated that in only in 1 of the 33 cases the predicted and true distributions disagreed.

In the tree height model, tree diameter was also the strongest explanatory variable (Table 5; III). The model concerning height to the lowest living branch showed similar results (Table 6; III). Stand and tree diameter and especially different height characteristics were used in this model. In the case of the lowest dead branch, only height to the first living branch could be used as a predictor (Table 6). This means that the applicability of this model is restricted to situations were some additional measurements in addition to normal stand mean characteristics are made. In all height models, the largest variation was the residual variation among trees in a plot. This is natural because sample trees represent different, and also extreme, positions in diameter distribution. The residual variation between stands was large for models for tree height and the lowest dead branch but in the case of height to the first living branch it was minimal

A taper polynomial was calculated using over bark diameters measured at relative heights. This was done after visual analysis of stem form, in which the data were sorted into one centimetre diameter classes, and average taper curves were calculated for each diameter class using the relative diameters at relative heights. The hypothetical assumption that relative diameters at relative heights - i.e. relative stem form - do not change much, was verified.

In most cases, when the taper curve approach is polynomial, a polynomial function has been based on the Fibonacci series (e.g. Laasasenaho 1982). In this study the combination of lower polynomial terms with one logarithmic term gave the best results. For grey alder, the polynomial taper curve function is presented in Equation 5 (III) and the parameter estimates and statistics for the taper polynomial are presented in Table 7 (III).

The basic taper polynomial (Equation 5; III) gives the same average stem form for all trees of different sizes. However, each tree has its own shape. Because there are certain regularities in the diameter differences at relative tree heights (Laasasenaho 1982), an adjusted basic model for a given tree can be generated as a function of the diameter at breast height and the total height of the tree (f(d,h)).

Differences between observed diameters and the basic taper polynomial (fb(x)) were calculated; and correction equations (cpli) were estimated for diameter differences at relative tree heights of 10, 40 and 70 % (Table 8; III). After the correction equations are applied, a cubic interpolation polynomial (Press et al. 1992; p. 114) can be calculated to pass through the calibration points. One extra point is needed for the tree top at relative height of 100 %, where the correction is 0. The final adjustment of the taper polynomial (fc(x)) is achieved by adding the corresponding coefficients of basic taper equation and interpolation polynomial (fr(x)) together: $f_c(x) = f_b(x) + f_r(x)$. The reliability of the taper polynomial as a volume predictor was tested in Study V.

The proportion of trees with rot at stump height seemed to vary irregularly as a function of age (Figure 2; III). The proportion of rot has its minimum value among the age classes of 30-50 years. A more unexpected result was that rot was more common in young age classes than in older ones. This could be a consequence of the regeneration in grey alder stands, because grey alder forests usually regenerate by sprouting from older trees. If the older trees are rotten, this means that some of the younger sprouts will also rot. In older age classes (over 50 years), the proportion of rotten trees increases as a function of rotation time.

The very smallest trees seemed to be healthy (diameter class 4 cm), but already in diameter class 6 cm the proportion of rotten trees was 50 % (Figure 3; III). Evidently, just at the beginning the proportion of rotten sprouts is small but later the amount of rot increases, e.g. as a consequence of harvesting damage (Norokorpi 1979).

The distribution of stands according to proportion of rotten sample trees in the stand is presented in Table 9 (III). Almost half of the stands had rot in less than 20 % of the sample trees. On the contrary, 10 % of the stands had rot in almost all sample trees.

By using the data collected, logistic regression models were constructed for predicting the probability of rot in stems. Explanatory variables were sought by calculating correlations between variables describing rot and other tree characteristics. Two models were constructed; the first ($i=1$) was made for predicting the probability of rot at stump height and the second ($i=2$) for predicting the probability of rot anywhere in a stem. The logistic model for calculating the occurrence of rot in grey alder stems is presented in Formula 3 (III) and the coefficients of Equations y_1 and y_2 are presented in Table 10 (III).

It can be deduced from the form of Formula 3 that the larger the value of the exponent the greater is the probability of rot in an individual tree. Considering the effects of the variables in Equation y1, the thicker the bark the greater is the probability that the tree has rot. The height of the lowest dead branch was also an indicator of rot; the higher the lowest dead branches are the smaller is the probability of rot. As was also seen in Figure 2 (III), the probability of rot decreases as age increases. In the case of Equation y_2, the effect of bark is similar to the previous case, but the effect of height of the lowest dead branch is opposite.

To be able to predict the length of rot in alder stems, two linear regression models were constructed (Table 11; III). The first was made for cases where the rot diameter at stump height was not known and the second for cases where it was known.

The reliability of the model without rot diameter at stump height as an explanatory variable was not very high. According to this model, the thicker the bark at 5 % height the longer is the rot in the stem, and the higher the first dead branch the shorter is the rot in the stem. Basal area was also statistically significant in this model. If the rot diameter at stump height is known, the reliability of the model is considerably better. In this particular model, the effects of the height of the lowest dead branch and basal area are similar to those in the previous model.

According to Study IV, there were fewer fresh knots in small-dimensioned grey alder butt and top logs than in larger grey alder logs. Especially in large top logs, there were considerably more fresh knots than in other types of logs. In all types of logs, fresh knots were concentrated to the section from 1.5 to 2.5 m (Figure 1; IV). Dry knots were concentrated at the base (0-0.5 m) of the logs and at a distance of 1.5-2.5 m (Figure 2; IV). There were almost twice as many dry knots in the top logs as in the butt logs. In large butt logs there were fewer rotten knots than in other types of logs. Rotten knots occurred most frequently in small-dimensioned top logs and were concentrated in the section from 0.5 to 2.5 m (Figure 3; IV).

Large top logs had more knots than other types of logs did. In large top logs, there were twice as many fresh knots as in small-dimensioned top logs. In general, top logs were more knotted than butt logs were, which was consistent with the process of self-pruning. Rotten knots were more common in top logs than in butt logs (Figure 4; IV). Average values for different grades show that the grades are not equally distributed throughout the log (Table 7; IV). Grade A, i.e. knot-free sawn timber was mainly at the base of the logs. In this respect grades B, C and reject differed from each other only slightly. In Table 8 (IV), the logs are divided into four grades. The limit values show that each grade occurred equally in logs.

Overall, it seems that in different types of logs the different grades were at the same distances. In the butt logs, grade C began noticeably farther away from the butt than in top logs. It also seems that the worse the grade was the greater was the length of the grade. So a rejected piece of sawn wood was usually rejected totally. The best grade A, was shorter than the other grades, and it could be combined with poorer grades (normally with grades B and C). The reasons for grade reductions are shown in Table 9 (IV).

Number of dry knots was the reason for reduction in sawn timber grade in half of the cases. This happens in every grade. Another very remarkable reduction was seen in quality rejected; discoloration was the reason for quality change in almost half of the cases.

One aim of this study was to investigate how suitable the quality classifications of Keinänen and Tahvanainen (Tables 2 and 3; IV) are. According to the classification (Table 2; IV), only 65 % of the logs could be classified to A, B or C grades and 35 % of the logs belonged to the log grade Rejected (Table 10; IV). The amount of log grade A was modest; only 7.7 % of the logs could be classified to grade A. 35 % of the saw logs were included in log grade B and 21 % in grade C.

When the results in Table 11 (IV) are compared to the log grades measured (Table 10; IV), the main difference is the small amount of Rejected sawn wood. The volume of grade A sawn wood is significantly greater than could be predicted from the log grading. In Figure 5 (IV) we can see the relation between grades of the logs and quality of the sawn wood. From the figure can be seen what kind of sawn wood could be obtained from different grades of logs (A, B, C, Rejected). We can also see the average distribution of sawn wood qualities.

From the grade-A saw logs we reached over 50 % grade-A sawn wood. The proportion of rejected sawn wood was very small (6 %). The sawn wood quality in log grades B and C do not differ. In both log grades the distribution of sawn wood grades is similar. The log grade Rejected includes the least grade-A sawn wood, but the volume of grades B and Rejected sawn wood are equal to the better sawlog qualities (B and C). Average amount of grade-A sawn wood in the sawlogs was 36 %, for grade-B 33 %, for grade-C 20 % and for the Rejected grade 11 %.

The correlation matrix between the main predictors is shown in Table 12 (IV). These 9 factors were used when the final models were built. The other factors, such as twist and cracks, were not significant, so the correlation matrix for them is not presented.

The largest correlations were between FK2 and DK1 and between FK1 and FK2. These correlations were taken into consideration when the regression models were built. The correlations between the predictors used in the models are smaller than +- 0.252 (between FK3 and TD). The regression models used for predicting the value for grey alder logs based on external quality are shown in Table 13 (IV).

The models were made in order to predict the value of different kinds of logs. There are separate models for butt and top logs. In the explanation of the models there are differences in interpretations. In Model 1 (IV) there were no significant external signs of quality that could be used in prediction; obviously, for the knot-free base section of a log the only external signs that can be used are dimensional (e.g. top diameter and length).

In Model 2 (IV) all the coefficients are negative, which means that all knots (fresh and dry) decrease the value of the stem. This is a direct result of preferring knot-free timber as the most valuable. Dry knots decrease the value more than fresh knots do. Of the quality signs, the knottiness at the section from 1.5 m to 2.5 meters is the most significant predictor. The standard error is smaller in Model 2 (IV) than in Model 1 (IV).

In Model 3 (IV) the coefficient of determination was larger than in Model 2 (IV). Top diameter of a log was included in Model 3 and the coefficient of determination improved slightly (37 %). The explanations for the coefficients in this model were logical; the top diameter increases the value of a log, and the dry and fresh knots decrease the value. As shown in Model 2 (IV), dry knots decrease the value more than fresh knots do. As in Model 2 (IV), the knotness from 1.5 m to 2.5 meters was the most significant predictor of value. Of these six models, the standard error for Model 3 (IV) was the smallest.

Model 4 (IV) gives the log value only according to the number of knots. The coefficients of determination for different variables are logical in interpretation. Both coefficients are negative, which indicates that knot-free timber is the most valuable. Dry knots influence the log value more than fresh knots do. In Model 5 (IV) the top diameter was included, which greatly increased the significance of the model. Here the coefficient of determination was 57 %, and the standard error was also smaller than in Model 4. Residual plots for the two most useful Models (3 and 5; IV) are shown in the Figure 6 (IV). The residual plot for top logs (incl. top diameter) has the smallest standard error (14.91). Model 5 (IV) has a large standard error but the residual is still symmetrical.

5.3 Volume tables for grey alder trees and logs (V)

The volume tables for grey alder are presented in Tables 6 - 9 (V). The volumes were determined as stem volumes with bark (dm^3) to an accuracy of one decimal for stems smaller than 100 dm^3 and to an accuracy of one dm^3 for stems bigger than 100 dm^3. A model was estimated for predicting the volumes without bark (Equation 10; V). The coefficient of determination for this model was 0.015 and the p-value for diameter was 0.035. The coefficient of determination was low, while the variation in bark thickness was high and the stem diameter did not have any significant influence on bark thickness (see Table 10). A model was also constructed for predicting the volume without bark at any height (Equation 11).

Previously, volume tables for grey alder have not been available. That is why the volume table for birch with bark (Laasasenaho & Snellman 1983) was chosen as a point of comparison for the whole tree-volume table (Table 7; V). The volume estimates for grey alder were smaller than the corresponding volumes for birch when the trees had large diameters ($d_{1.3} > 15$ cm) but low heights ($h < 10$ m). Then the volumes for grey alder in larger diameter classes are at most 10 percent smaller than for birch of the same size. Considering tall but small-diameter trees, larger volumes are obtained by using the volume tables for grey alder compared with the volume tables for birch. The differences are 11 % at most. This difference decreased to 6 % when the length of the trees was 20 m and diameter at breast height 20 cm. Both these examples were taken from the extreme volumes, where the values can be considered to be extrapolated. According to these new volume tables for grey alder and the tables for birch, the volumes for grey alder showed similar volumes in the middle-size trees ($d_{1.3} = 10$ cm, $h = 10$ m). Due to the small amount of data in the diameter classes more than 20 cm, the usability of volume estimates for grey alder stems larger than 20 cm must be considered carefully (Table 2; V).

5.4 Theoretical calculation for the processing value of grey alder (II, III, IV, V)

The example forest

An example forest was calculated in order to calculate the amount of logs and pulpwood. The calculation was made by using the models presented in Articles III and V. The diameter distribution was calculated by using the Weibull function (Table 4, III). The tree-height mixed model used is presented in Table 5 of Article III. The grading system of Keinänen and Tahvanainen (1995) was used for the logs (minimum length 2.1 m and minimum top diameter 13 cm). The calculation is presented in Table 5.

Table 5. Calculation of the example forest (area 1 ha, basal area 28 m^2/ha, H_{dom} 15 m).

Diam. class (cm)	Height (m)	Freq.	Freq. * basal area	Volume of one tree (dm^3)	Volume of one class (dm^3)	Log-%	Log volume (dm^3)	Pulpwood (dm^3)
4.00	5.92	0.00	84.63	4.48	378.84			378.84
6.00	8.63	0.03	278.15	12.10	3364.34			3364.34
8.00	10.54	0.06	319.89	25.39	8120.75			8120.75
10.00	11.91	0.08	299.71	44.51	13339.26			13339.26
12.00	12.94	0.10	258.08	68.94	17791.04			17791.04
14.00	13.74	0.12	210.40	97.96	20611.00	34	7007.74	13603.26
16.00	14.37	0.12	163.92	131.07	21484.65	62	13320.48	8164.17
18.00	14.88	0.11	122.41	168.17	20586.03	76	15645.38	4940.65
20.00	15.31	0.10	87.68	209.74	18389.79	83	15263.52	3126.26
22.00	15.66	0.08	60.22	256.84	15468.39	88	13612.19	1856.21
24.00	15.97	0.06	39.64	311.29	12340.07	90	11106.06	1234.01
26.00	16.23	0.05	24.98	375.74	9387.57	94	8824.31	563.25
28.00	16.46	0.03	15.06	453.94	6838.57	94	6428.26	410.31
30.00	16.66	0.02	8.68	551.19	4786.02	94	4498.85	287.16
32.00	16.84	0.01	4.78	674.96	3226.32	94	3032.74	193.58
34.00	17.00	0.01	2.51	835.94	2099.28	94	1973.32	125.96
36.00	17.15	0.00	1.26	1049.65	1320.68	94	1241.44	79.24
38.00	17.27	0.00	0.60	1339.05	804.43	94	756.16	48.27
40.00	17.39	0.00	0.27	1738.65	474.93	94	446.44	28.50
42.00	17.50	0.00	0.12	2301.27	272.04	94	255.72	16.32
					181083.99		103412.61	77671.38
Total volume (m^3)		**181.08**						
- logs		103.41						
- pulpwood		77.67						

According to the models used, the volume of the simulated alder stand is 181.1 m³ / ha. Of that volume, 103.4 m³ are logs and 77.7 m³ pulpwood.

When calculating the round wood price at the sawmill, we must include the estimated selling price of the end product or the onward selling price of the timber in the calculation. An example for calculating the timber price at the sawmill was presented in the dissertation of Pöyhönen (1991). The method of calculating the timber price at the sawmill includes the following steps:

1. The price of the sawn timber at the delivery storage.
2. The sales costs, sales rewards, reclamation costs, shipping and forwarding costs, delivery costs and transport costs from the sawmill to the delivery stock are subtracted from the sawn timber price.
3. The sales proceeds of the by-products at the sawmill are added.
4. As a result the product price at the sawmill is obtained.
5. The variable costs in the production are subtracted: product stock costs, manufacturing and repairing costs including social security costs, energy costs, by-raw material costs, material costs and chemical costs.
6. Fixed costs of the saw mill are subtracted: administration wages including social security costs, rents, insurances, office costs and other social costs.
7. Capital costs are subtracted: rate costs, depreciations which correspond to operating time of the machines and taxes.
8. The profit of the enterpriser is subtracted.
9. The final result is the raw material expenses at the sawmill.

When the raw material expenses (FIM/m³) are divided by the utilization factor (m³ round wood / m³ sawn timber), the price of one cubic meter of round wood at the storage of the sawmill is obtained. The statistical values used were collected from studies of Lallukka (1986), Ryti (1987), Heino (1988a,b), Pöyhönen (1991), Louna & Valkonen (1995), Kärki (1997) and Metsätilastollinen vuosikirja (1998). The values do not describe any particular sawmill. The numbers are intended to show the relationship between different factors in a situation where the processing of the example products is profitable. Furthermore, the sawmill is intended only for primary processing only and is expected to be located somewhere in eastern Finland. The logging costs used in the calculation are presented in the study of Kärki (1995). Overhead costs of the wood procurement include rates, administration, management, fixed assets and social costs. The long-distance transport costs are calculated by using lorry transport (90 km) and logging costs consist of felling and processing, forwarding, additional costs and social costs.

The volumes of different sawn timber grades are calculated according to Figure 5 and Table 5 in Article IV and the volumes of different sawlog qualities according to Table 10 in Article IV. The logs are sawn unedged (i.e. by flat slicing) followed by subsequent drying and ripping. Sawn wood is edged after drying. The variable costs in sawmilling include the costs of log storage, sawmilling, the sawn timber yard, drying, steam, power, running, material, repairing and social costs. The fixed costs consist of office, rent, car, insurance, administration and social costs and the capital costs include depreciations, rates and taxes.

Table 6. Calculation of the unit price of sawn timber at the sawmill and stumpage price of saw logs.

	VOLUMES m^3	PRICE FIM/m^3	VALUE FIM
VOLUME OF THE EXAMPLE FOREST	181		
- saw log volume	103.40		
- pulpwood and slash	77.60	100	7760
AMOUNT OF SAWABLE LOGS			
- saw log volume	103.40		
- grade A	7.96		
- grade B	37.12		
- grade C	21.82		
- pulpwood, slash	36.50	100	3650
Incomes from pulpwood and slash			11410
AMOUNT OF SAWN TIMBER			
Amount of saw log to the sawmill, qualities A. B and C	66.90		
- amount of sawn timber (yield 36.5 %)	24.42		
- quality A	10.49	2000	20983
- quality B	9.31	1300	12097
- quality C	4.62	500	2310
- pulpwood, slash	14.38	50	719
- bark (10 %)	6.69	50	334
- sawdust (5 %)	3.34	50	167
			36612
The average sawn timber price / m^3	**1499**		

Table 7. Calculation of the stumpage price (FIM/m^3).

THE STUMPAGE PRICE	**VALUE, FIM / m^3**
Price of sawn timber on average	1499
Sales and delivery costs	65
Price of the sawn timber at the sawmill	1434
Sales of by-products	100
Sales proceeds (net)	1534
Reduced:	
Production costs	
Variable costs	683
Fixed costs	80
Production costs in total	763
Capital costs	50
Profit of the enterpriser	30
Total	843
Left for raw material costs	691
Left for saw log in storage	253
THE STUMPAGE PRICE FOR SAW LOG WITH BARK	
Price at the sawmill	253
Reduced:	
Overhead costs of the wood procurement	10
Long-distance transport costs	40
Logging costs	45
TOTAL	95
STUMPAGE PRICE	**158**

The stumpage price according to the example calculations is 158 FIM/m^3 (Tables 6 and 7). The stumpage price can change considerably, e.g. according to dimension and grade of the logs, wood procurement costs, production costs and, last but not least, the market price of lumber.

Costs of furniture manufacturing

The costs of manufacturing furniture from grey alder are calculated in Table 8. This calculation is made in order to evaluate the reliability of the calculated stumpage price. The product and operating concept of the example factory used in the calculations is presented by Juva & Ahtorinne (1995). The model factory is a typical plant manufacturing wooden dining-room tables and chairs. The calculation made here adapts the concepts used in those calculations. Some key points of the operation concept are:

- there is one basic furniture model in the production, which is slightly modified for different products
- products are gathered in the store or at the customer's home
- the main raw material is solid hardwood; tags and other materials are carefully standardized
- the timber is bought as kiln-dried sawn timber

The cost distribution at the example factory is presented in Figure 7.

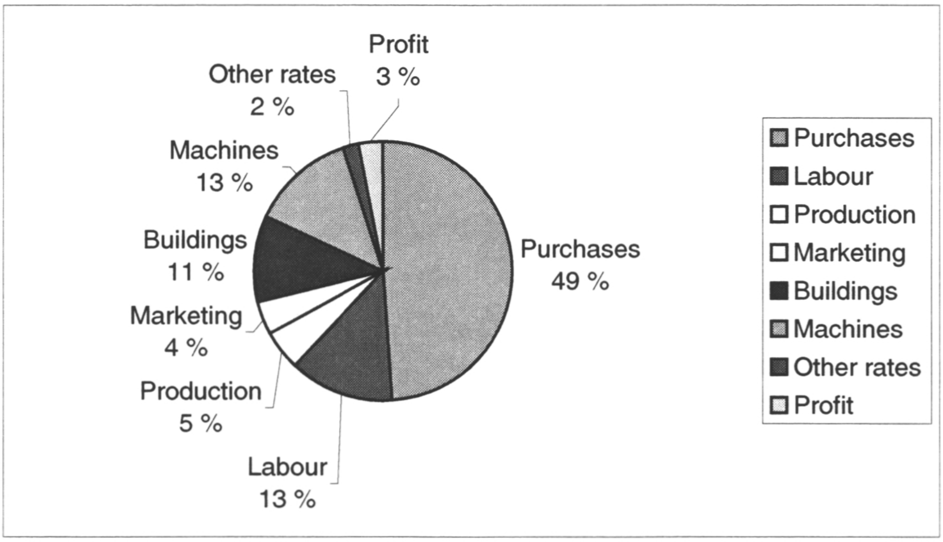

Figure 7. Cost distribution at the example factory.

The calculation for manufacturing wooden chairs from grey alder and the costs of transportation and trade in furniture marketing for German markets is presented in Table 8. The estimated need for raw material is 0.035 m³ (chair), but 0.05 m³ is used in the calculation (Juva & Ahtorinne 1995). The price of grey alder sawn timber in the calculation is 2 500 FIM/m³.

Table 8. Calculation for manufacturing wooden chairs from grey alder and the costs of transportation and trade in furniture marketing.

MANUFACTURING	**COSTS FIM/chair**
Wood material 44 %	145
Other materials 5 %	17
Labour 13 %	43
Production costs 5 %	17
Marketing costs 4 %	13
Buildings 11 %	36
Machines 13 %	43
Other rates 2 %	7
Profit 3 %	10
PRICE OF THE PRODUCT AT THE FACTORY	**330**
TRADE	
Freight 50 FIM	380
Marginal of the wholesale and retail trade 30 %	522
VAT 16 % (Germany)	624
Price of the product	639
MARKETING PRICE OF A WOODEN CHAIR FROM GREY ALDER	**639**

6 DISCUSSION

The high percentage of interested companies in the questionnaire made in Study I, can be partly explained by the fact that the companies which were not interested in using special timber did not answer the inquiry as enthusiastically as those that were interested. If we suppose that all companies in Savo-Karelia which were interested in the processing of alder replied to the inquiry, the real estimate of those interested would be 18 % (answering percentage 0.25 x percentage of all companies interested in the inquiry 0.70). According to this calculation, at least every fifth wood-processing company in Savo-Karelia is interested in processing special timber, including alder. The real percentage of interest can probably be found between these two extreme values.

Even though all types of furniture stores were included in the material of Study II, the most important source of error was the subjective sampling of advertisements. Along with the geographical concentration of the sampled material (economic area of Munich), this permits only limited possibilities to apply the results elsewhere in Central Europe. Unfortunately, the furniture purchasers were not interviewed; interviews would have made possible a detailed comparison between advertising arguments and purchaser requirements. Nevertheless, the material gives an indication of furniture markets in southern Germany. When the results are compared to other European countries, e.g. Finland, the marketing of wooden furniture differs greatly. In Finland, the furniture is marketed as good value for money, rich in selection and domestic (Pakarinen & Turunen 1999); whereas in Germany the design of the furniture, tree species and pro-environmental aspects are highlighted. For solid-built furniture, the difference in marketing between Finland and Germany is even greater. When „green values“ and tree species are used in the argumentation, the advertiser wants to highlight pro-environmental thinking. Altogether, in Central Europe considerable amounts of alder timber are used for furniture. In Study II, alder was defined as the fourth most popular tree species for all types of furniture. According to Euwid Magazin (Massivhölzer … 1995), in 1995 alder was ranked as the sixth most popular tree species in German markets. This is consistent with the results of Study II, if we assume that, as seen from the import figures (Figures 4 and 5), the use of alder timber has increased.

The prediction of branch-height characteristics, especially height to the first dead branch in Study III, proved problematic, due to the poor correlation between these characteristics and other tree dimensions. This has also been found for other tree species (e.g. Rouvinen et al. 1997, Verkasalo 1997 and Uusitalo and Kivinen 1998). When tree quality is considered, however, branch-height characteristics are important. Rouvinen et al. (1997) proposed that average branch-height characteristics should also be measured in field inventories when other stand characteristics are collected. These variables could then be generalized directly for all trees in the stand. This was also tested in Study III but the results were not good. Using non-parametric kernel-smoothing, Uusitalo and Kivinen (1998) developed a system for describing bivariate tree diameter and height to the distribution of the first dead branches. The benefits of this kind of approach are especially important in situations where the correlation structures between certain characteristics are complex (Silverman 1986). However, these non-parametric methods require measurement of several sample trees per stand and could thus not be used for the material of this study.

When the reliability of the polynomial taper curve for grey alder (Model 3; V) was tested, the estimated relative bias and the standard error of the stem volume estimates were about 0.4 % and 9.0 %, respectively. Laasasenaho (1982) found that when the taper polynomial based on Fibonacci series was used, the estimated relative standard error of the volume estimates varied from 7.2 to 8.5 % for pine, spruce and birch. A good starting point for analysis of reliability is to compare volume estimates calculated with a taper polynomial to those estimated using a volume function. A simple non-linear volume function for grey alder has been presented in Study V using the same data as that used in Study III for the taper polynomial. These two methods gave almost the same estimates of total stem volume. The taper polynomial was a more reliable and stable estimator, especially in the largest diameter classes.

Rot is more common in grey alder than in spruce. Mäkelä (1990) studied the probability of rot in Norway spruce stems. If we compare the results of the Study III to those of Mäkelä, some interesting differences can be seen. The proportion of rotten trees according to age classes was opposite in these two studies; in Norway spruce stands the proportion of rotten trees was smallest in the beginning of the rotation time, while in alder stands the proportion was smallest in the middle of the rotation time. The difference in alder stands could be explained as being due to the way alder regenerates (sprouting). There is another obvious difference in the diameter classes; the proportion of rotten Norway spruce is lowest in large diameter classes, while in alder stands the proportion of rotten trees is highest in large diameter classes. When results for the proportion of rotten trees at stump height in different age classes are compared to white birch (*Betula pubescens*) (Verkasalo 1997), the proportion of rotten grey alder stems in different age classes is significantly lower than in white birch. According to Verkasalo (1997), the proportion of rotten white birch trees (rot in the log or pulpwood) younger than 40 years ranged from 32 % (seed born) to 45 % (sprout born) (grey alder 36 %, Figure 2; III), at 41-60 years 37-53 % (grey alder 29 %) and over 61 years 45-61 % (grey alder 33 %). This is a significant result because it is normally thought that in Finland rot is much more common in grey alder than in other hardwood species.

When Norokorpi (1979) investigated how the length of the rot in spruce stems correlates with $D_{1.3}$ and the age of the tree, he found these correlations to be linear. In that study the volume of the trees and the volume of the rot were also compared and found to be exponential. Tamminen (1985) studied detection of butt-rot in standing spruces. The variables used described the form and growth of the stem of the sample trees (e.g. diameter increment at 1.3 m height during the last 10 years). The success rate in the prediction model was 68 %, which is comparable to the results of Study III. Mäkelä (1990) also obtained similar results for spruce; the success rate for prediction of rot in a tree was 60 %. According to these studies, the success rates (73 and 67 %) found in Study III, can be considered good.

In general, according to Study IV, grey alder logs have knots from the base to the top. All types of knots appear and the length of the knot-free section at the base is short. The difference between a dry-knot section and a fresh-knot section is not as obvious as, for example, for pine or even birch (Kärkkäinen 1986). In small-dimensioned logs, there are fewer knots than in larger logs. Especially in large top logs, there are many more fresh knots than in other types of logs. It is interesting that dry knots are concentrated at the base of the logs (0-0.5 m) and in the section from 1.5 to 2.5 m. The number of dry knots in top logs is almost twice that in the butt logs. Rotten knots are concentrated in the section from 0.5 to 2.5 m.

Small-dimensioned butt and top logs are less knotty than large logs. If we compare these numbers of knots to the grade classification presented in Table 2 (IV), both averages could be included in grade-B. Large butt logs could be classified as grade-C and large top logs in the rejected category. Nevertheless, this is only a classification according to knottiness, in which the other quality factors (sweepness, crooks, cracks, discoloration etc.) are not taken into consideration. Overall, in different types of logs, it seems that the different grades are located in comparable sections along the length. It also seems that the worse the grade was, the longer was also the length of the grade. The most common reasons for decreasing grade were dry knots and discoloration.

When the models for predicting the value of grey alder logs are considered, three models seemed to be valid: models predicting the value for butt logs (Model 1; IV), top logs including top diameter (Model 3; IV) and all logs including top diameter (Model 5; IV). Models 2 and 4 (IV) (based only on number of external knots) were also logical, but the standard errors were slightly higher because the top diameter was not included.

The most important source of error in the material of Study IV was the subjective sampling of experimental trees by two loggers. Those trees obviously were not average trees in the stands as far as quality was concerned. On the other hand, according to the grades in Table 2 (IV), they were the best and largest trees. The measurements were made from only two stands. Along with the geographical concentration of the material, this permits only limited possibilities to apply the results elsewhere in Finland. Nevertheless, the material gives an indication of the quality of grey alder logs in the Savo-Karelia area.

Unfortunately, the size of the knots (except classification) was not taken directly into account when the logs and timber were classified; if they had been, it would have permitted more detailed analysis of the knot distribution in different kinds of logs. The knots were measured only partly in order to classify the logs and sawn pieces correctly. The grading used for grey alder logs and sawn timber (Tables 2 and 3; IV) is also one source of error, because it is based on theoretical assumptions and the grade limits are fixed without empirical studies. This causes error when the grading is used for value predictions. Despite these possibilities for error, the reliability of the results can be considered good: one aim of the research was even to investigate the suitability of the classification (Tables 2 and 3; IV) to practise.

In Article V, the theoretical calculated log volumes for grey alder were calculated according to three different classification criteria (Tables 6–9; V). It was concluded that the different dimension criteria greatly influence the theoretical estimates of log volume. When the volumes were estimated according to the minimum dimensions of Keinänen & Tahvanainen (1995) (Table 2; IV), the volumes were much smaller than when estimated with the criteria presented in Study I (Table 13; I); e.g. a grey alder stem of 14 cm diameter has to be 11 m tall to be able to produce a log with the dimension criteria 13 cm / 21 dm and even 18 m tall with dimension criteria 13 cm / 30 dm. With the dimension criteria 8 cm / 20 dm, a grey alder stem of 14 cm diameter produce a log as 7 m tall. It must be noted that the use of small dimensions in log criteria also means that the stem form must be straight so that the logs can be sawn.

The bark volume of grey alder stems was also investigated in Study V. According to Table 10 and Model 10 (V), the proportion of bark increases as the diameter of a grey alder stem grows. The result is opposite to e.g. that of Mäkinen (1984). The difference could be explained so that in the study of Mäkinen the largest grey alders were less than 15 cm in diameter, whereas in Study V some stems were nearly 30 cm.

The price from the calculation presented in Table 7, gave a stumpage price of 158 FIM/m³. This result is a computational price based on average estimates. However, this price gives an indication of a reasonable price level for grey alder timber in Finland. It was also shown in the furniture manufacturing calculation that the raw material price for alder is not yet the limiting factor (Table 8). The price limit for good quality alder sawn timber could be 3 000 FIM/m³.

There are few studies and statistics concerning the prices of alder timber. In the study of Louna & Valkonen (1995) the computational price for alder timber for Finnish markets is calculated using the Swedish markets for hardwood logs in 1993 as a basis. The stumpage price for alder is calculated so that the price relation between birch and alder in Sweden was used for Finnish conditions using the Finnish birch price. The stumpage price of alder logs in Finland was calculated to be 152 FIM/m³. In this case the stumpage price for birch in Finland was 200 FIM/m³. If we assume that the price relations between hardwood logs in Sweden are nowadays the same as in year 1993, we can calculate the alder stumpage price by using the newer price for birch in Finland (263 FIM/m³). In this case, the computational stumpage price for alder in Finland would be 200 FIM/m³, which agrees well with the calculated price in this study (Table 7). In year 1993, according to Louna & Valkonen (1995), the stock price for black alder was 150-280 FIM/m³ and for grey alder 100-160 FIM/m³. In the same study, the price of unedged alder sawn timber was estimated to be 1 200 - 2 500 FIM/m³.

We can use the same methodology also for the German prices. It must be noticed that in this calculation we compare log prices from two different countries where the wood procurement and general price level is quite different. The price index between hardwood logs (B-quality) are calculated using the price levels in the state forests of Baden-Württemberg and Bayern in 1997/98 (Jahresberichte der Baden-Württembergische und Bayerische Staatsforsten 1998 and Metsätilastollinen vuosikirja 1998). The German prices for logs include logging, so to the Finnish price for birch sawlogs is added 50 FIM/m³ for logging costs (263 FIM/m³ + 50 FIM/m³ = 313 FIM/m³). The birch prices are averages for silver and white birch, and the alder prices are average for black and grey alder. The calculated computational prices for hardwood logs in Finland in 1997/98 would then be for alder 417 FIM/m³ (index 133 compared to birch), beech 413 FIM/m³ (132), oak 635 FIM/m³ (203) and poplar and aspen 182 FIM/m³ (58). This way calculated price for alder logs, 417 FIM/m³, seems to be very high compared to the price calculated in this research (Table 7).

When the calculation for alder processing value is evaluated (Tables 5, 6, 7), attention must be focused on certain aspects. Firstly, the figures used in the calculations are average. Secondly, the processing value can vary significantly if the different values used in the calculation change. Thirdly, when alder is processed, by-products are very important; a decrease in pulpwood / firewood price significantly decreases the processing value of alder stems.

7 CONCLUSIONS

This dissertation covers many aspects of the procurement and mechanical processing of grey alder wood in Finland. These topics should, however, be studied more and developed further before a profitable level of utilization can be reached for grey alder. According to the results of this dissertation, there are potential markets for grey alder timber both in Finland and in Central Europe. The willingness of small- and middle-sized sawmills to process grey alder as one of their raw materials was a very significant finding. The results concerning the stand and wood quality of grey alder were also positive; there is a potential for mechanical wood processing of grey alder harvested from existing forests. This means that this species can be cultivated in Finland if grey alder forests are treated with goal-directed silvicultural methods, not selection thinned, as has been the practise until now.

In addition, new information is given in this dissertation concerning the quality of grey alder stands and estimates of the saw log quality needed in practise to provide raw material for sawmills. The focus of this research was on grey alder forests and mechanical wood processing in eastern Finland, but the results can also be applied to certain conditions in other parts of the country. Moreover, the models for tree quality and volume can contribute indirectly to the increased utilization of alder timber.

In conclusion, further research is needed if the use of grey alder is to be intensified. Relevant topics include: 1) properties and utilization of by-products, 2) organization and techniques for procurement of grey alder timber, e.g. in cooperation with a large wood supplier, 3) development of silvicultural methods for grey alder and 4) the mechanical and physical properties of grey alder for wood processing (e.g. drying, machining, gluing, surfacing).

The management and utilization of grey alder as a profitable tree species is just beginning to develop in Finland. There is already an abundance of grey alder stands in certain parts of the country where stems could be raised to valuable timber. The use of alder must be seen as an addition to the main Finnish tree species, pine, spruce and birch. Grey alder timber could be one of the main materials used at small sawmills that concentrate on carefully selected special products. So, why not use silvicultural methods to raise this species and then process it for profit ?

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I

Timo Kärki

Timo Kärki

Sahauskelpoisen erikoispuun laatuvaatimukset ja käyttö Savo-Karjalan alueella

Kärki, T. 1997. Sahauskelpoisen erikoispuun laatuvaatimukset ja käyttö Savo-Karjalan alueella. Metsätieteen aikakauskirja – Folia Forestalia 1/1997: 37–48.

Tutkimuksessa on analysoitu Suomessa vähemmän käytettyjen puulajien, ns. erikoispuulajien, laatu- ja mittavaatimuksia sekä käyttöä Savo-Karjalan alueella. Työssä käsitellyt puulajit ovat laadukas mänty, kuusi ja koivu sekä lehtikuusi, kataja, haapa, leppä, pihlaja ja Suomessa luontaisena kasvavat jalot lehtipuut.

Erikoispuulajeille muodostettiin Savo-Karjalan alueelle tehdyn yrityskyselyn perusteella kolmiluokkainen laatu- ja mittaluokittelu (luokat A, B ja C). Laatuluokittelussa on käytetty sanallista arviointia vikaisuuksien määrittelyssä ja mittavaatimuksissa on annettu kussakin luokassa minimiläpimitta- ja minimipituusvaatimukset tavaralajimenetelmällä valmistetulle erikoispuutavaralle.

Yrityskyselyn tulosten perusteella suhtautuminen erikoispuun käyttöön Savo-Karjalassa on positiivisen kiinnostunutta. 70 % kyselyyn vastanneista yrittäjistä on kiinnostunut laajentamaan tuotantoaan erikoispuulajeihin, jos niitä on vain saatavissa. Kiinnostavimmat puulajit ovat leppä sekä haapa. Pääkomponenttianalyysilla saatiin neljä erilaista tekijää, jotka ovat ratkaisevia erikoispuun käytön aloituksessa tai käytön lisäämisessä (uusi tuotantomahdollisuus, erikoispuunhankinta, markkinat, kehittämisprojektit). Vastanneet yrittäjät haluavat kehittää puunhankintaansa tulevaisuudessa omana hankintanaan tai metsänomistajan suoraan toimittamana.

Asiasanat: erikoispuulaji, puupörssi, laatuvaatimukset

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1 Johdanto

1.1 Yleistä

Suomessa puun teollinen käyttö on keskittynyt kolmeen suureen pääpuulajiin eli mäntyyn, kuuseen ja koivuun. Muiden kotimaisten puulajien käyttö on ollut huomattavasti vähäisempää. Haapaa ja leppää on käytetty aikakaudesta riippuen vaihtelevia määriä, mutta muiden puulajiemme kuten pihlajan, tammen, saarnen, jalavan, vaahteran ja lehmuksen käyttö on ollut hyvin vähäistä (Louna ja Valkonen 1995). Vähemmän käytettyjen puulajien kohdalla onkin puhuttu erikoispuulajeista ja erikoispuista.

Markkinoilla liikkuvan kotimaisen erikoispuun määrä on marginaalinen. Eniten käytetyt erikoispuulajit ovat visakoivu, haapa, leppä sekä lehtikuusi. Jalojen lehtipuiden kohdalla kotimaisen raaka-aineen määrä on rajoitettu, yhteismäärältään alle 200 m^3 pyöreää puuta vuodessa (taulukko 1). Samanaikaisesti lehtipuusahatavaraa (poislukien koivu) tuotiin Suomeen (v. 93) noin 35 000 m^3 (Louna ja Valkonen 1995).

Annettuihin lukuihin on kuitenkin syytä suhtautua varauksella, koska Lounan ja Valkosen (1995) tutkimuksessa olivat mukana vain yli 20 työntekijän yritykset sekä pienemmistä yrityksistä satunnaisesti 10 % otos.

Viime vuosina on mielenkiinto lisääntynyt harvinaisempien kotimaisien puulajien käyttämiseen rakentamisessa ja kodin sisustuksessa. Aiheesta on käyty vilkasta keskustelua alan lehdissä ja useita erikoispuun käytön kehittämistä edistäviä hankkeita on käynnistetty (mm. Puu-Suomi -projektissa 1992–1994). Alueellisiin kehittämisprojekteihin on liittynyt myös erikoispuupörssin perustaminen, jonka avulla on tehty pienimuotoista erikoispuun kauppaa. Tällaisia puupörssejä on toiminnassa Iisalmen seudulla, Pohjois-Karjalassa, Itä-Hämeessä, Satakunnassa ja Länsi-Uudellamaalla. Kuitenkin esim. Pohjois-Karjalan Erikoispuupörssin toimintaa on vaikeuttanut erikoispuun yleisten laatu- ja mittavaatimusten puuttuminen (Saramäki Matti, Pohjois-Karjalan mhy:sten liitto 1994). Puupörssin toteuttamista ja vaikutuksia puukaupan logistisiin palveluihin ovat tutkineet Vepsäläinen ja Kuula (1992) julkaisussaan ja puupörssin toimintaan ovat paneutuneet Kallio ja Salo (1992) ja Kuula ym. (1992).

Taulukko 1. Erikoispuun käyttömäärät vuonna 1993. Mukana ei ole polttopuukäyttöä. (Verkasalo 1993a, Louna ja Valkonen 1995)

Puulaji	Käyttömäärä
Visakoivu	Muutamia satoja tuhansia kiloja
Haapa	Haapatukki: 10 000–15 000 m^3
	Haapakuitu: 100 000–150 000 m^3
Leppä	Leppätukki: Muutamia tuhansia m^3
	Leppäkuitu: Muutamia kymmeniä tuhansia m^3
Lehtikuusi	1 000–2 000 m^3
Tammi	Alle 100 m^3
Pihlaja	Muutamia kymmeniä m^3
Vaahtera	Muutamia kymmeniä m^3
Lehmus	Muutamia kymmeniä m^3
Saarni	Muutamia m^3
Jalava	Muutamia m^3

Erikoispuu-käsitteeseen liittyvää suomalaista tutkimuskirjallisuutta on ollut saatavilla niukasti. Kattavia puulajien ominaisuuksia käsitteleviä perusteoksia on julkaistu (Salmi 1972, 1977, 1978, Uusvaara ja Pekkala 1979, Mali 1980), mutta itse erikoispuun käytöstä puuttuvat kattavat tutkimukset. Lehtikuusen kohdalla tilanne on poikkeava, sillä lehtikuusesta on tehty Suomessa muita erikoispuulajeja huomattavasti kattavampi tutkimusten sarja jo melko pitkän ajan kuluessa (Vuokila 1960, Hakkila ja Winter 1973, Sairanen 1982, Tuimala 1993, Verkasalo 1993a, 1993b). Haavan ominaisuuksia ovat tutkineet Tikka (1954, 1956), Kärkkäinen (1980, 1981), Kärkkäinen ja Salmi (1978), Opdahl (1989, 1991), Verkasalo (1990), leppää Schalin (1966), Alestalo ja Hentola (1967), Lehtonen ym. (1978), Björklund ja Ferm (1982) ja visakoivua Saarnio (1976). Aivan viime aikoina on kiinnostus muidenkin erikoispuulajien käyttöön herännyt ja muutamia julkaisuja aiheesta on tehty (Palen 1994, Keinänen ja Tahvanainen 1995, Louna ja Valkonen 1995, Valkonen ym. 1995).

Suomessa erikoispuun käyttöä on tarkasteltu muutamassa tutkimuksessa. Louna ja Valkonen (1995) toteavat lehtipuiden käytöstä, että teollisuussahat asettavat lehtipuutukeille yleensä samankaltaisia laatuvaatimuksia kuin havupuutukeille. Pienyrittäjät sen sijaan kelpuuttavat sahattaviksi myös huo-

Taulukko 2. Luttisen (1994) tekemässä tutkimuksessa annettuja mittavaatimuksia haavalle ja lepälle. Osassa järeys- ja pituusmitoista on annettu vain minimimitat eikä maksimidimensiolle ole annettu ylärajaa.

Puutavaralaji	Järeysaste (cm)		Pituus (m)	
	Min	Max	Min	Max
Haapatukki	15	30	3,0	–
	20	40	3,0	–
	23	40	1,7	–
Leppätukki	8	–	3,0	6,1
	13	40	2,7	–
Haapakuitu	15	30	3,0	–
Leppäkuitu	8	–	2,0	3,0
	15	30	3,0	–

nolaatuisia ja pienikokoisia tukkeja. Minimimitoiksi lehtipuutukeille annetaan tutkimuksessa yleisesti läpimitan osalta 14–20 cm sekä pituuden osalta 1,5–3 m.

Luttinen (1994) on tutkinut Ylä-Savon puupörssiä varten kyselytutkimuksella yrittäjien mielestä eri puutavaralajeille soveliaimpia järeysasteita ja pituuksia. Tutkimuksessa olivat mukana myös leppä ja haapa. Pienimuotoisessa tutkimuksessa (vastaajia 21) muutamien yrittäjien antamia mittavaatimuksia esitellään seuraavassa taulukossa (taulukko 2).

Tutkimuksen mukaan yrittäjät haluavat haapatukin järeämpänä kuin leppätukin. Tämä johtunee osittain siitä, että harmaaleppä jää jo luonnostaan pienemmäksi kuin haapa ja tervaleppä. Pituuden osalta yrittäjät ovat melko yksimielisiä 3,0 m minimipituudesta.

Erikoispuiden laatu- ja mittavaatimuksia käsitteleviä tutkimuksia löytyy lähinnä saksankielisestä kirjallisuudesta. Laatutunnuksia ovat puulajeittain ja käyttötarkoituksittain tarkastelleet Knigge ja Schulz (1966), Steuer (1979), Grammel (1989) ja pituus- ja läpimittavaatimuksia Eisele (1989a, 1989b, Rohholzsortierungsbestimmungen ... (1993). Saksalaisesta luokituksesta on huomattava, että luokitus keskittyy runkomenetelmällä apteerattujen runkojen arviointiin.

1.2 Erikoispuulajin ja -puutavaralajin käsite

Metsissämme esiintyy luontaisena kolme havupuuja neljätoista lehtipuupuulajia: euroopanmarjakuusi, mänty, kuusi, haapa, rauduskoivu, hieskoivu, tervaleppä, harmaaleppä, metsätammi, vuorijalava, kynäjalava, kotipihlaja, suomenpihlaja, ruotsinpihlaja, vaahtera, metsälehmus ja saarni (Salmi 1972, Holmåsen 1991). Osa näistä puulajeista on hyvin rajoitetusti tietyllä kasvualueella esiintyviä, joka sinällään rajaa ko. puulajit erikoispuiksi.

Suomeen on aikojen kuluessa tuotu vierasta alkuperää olevia puulajeja, joita esiintyy nykyisin maassamme. Näistä puulajeista taloudellisesti merkittävimpiä ovat euroopan- ja siperianlehtikuusi. Näiden puulajien alkuperä ei ole kotimainen, joten ne täyttävät toisen erikoispuu -käsitteen rajaavan tekijän eli esiintyvät luontaisen kasvualueensa ulkopuolella ja ovat sopeutuneet fysiologisesti maassamme vallitsevaan ilmastoon.

Lisärajoite erikoispuu -käsitteelle on ko. puulajin pieni osuus metsäpinta-alasta ja vuotuisesta kasvusta. Männyn osuus Suomen metsäpinta-alasta vallitsevana puulajina on 61,9 % ja kuusen 27,1 % (Metsätilastollinen vuosikirja 1992). Metsiköitä, joissa koivu on vallitsevana puulajina on 7 %. Lepän ja haavan osuudet ovat 0,5 % ja 0,3 %. Muille havu- ja lehtipuille on metsälautakunnittain saatu prosentin kymmenyksen suuruisia arvoja; tilavuudella mitattuna erikoispuulajien suuruusjärjestys hieman muuttuu. Louna ja Valkonen (1995) ovat laskeneet Valtakunnan metsien 8. inventoinnin (VMI8) perusteella Etelä-Suomen lehtipuun kokonaisvarannot ja tukkivarannot puulajeittain (taulukko 3).

Taulukosta nähdään, että haapa ja leppä ovat kokonaistilavuudeltaan samaa luokkaa. Suhde leppälajien sisällä on suuresti harmaalepän puolella. Koivulajeissa hieskoivua on koivuvaroistamme merkittävästi enemmän kuin rauduskoivua. Muiden lehtipuiden osuus kokonaispuuvaroistamme on hyvin pieni, alle 4 milj. m^3 Etelä-Suomen alueella. Vastaavasti esim. männyn kokonaistilavuus samalla alueella on 500,2 milj. m^3 (Metsätilastollinen vuosikirja 1992).

Erikoispuu -käsitettä rajaava tekijä on myös puuaineen erikoiset rakenteet ja ominaisuudet. Tällaisia ominaisuuksia ovat visaisuus ja laineellisuus

Taulukko 3. Etelä-Suomen lehtipuuvarannot Valtakunnan metsien 8. inventoinnin (VMI8) mukaan. Määrät 1000 m³. (Etelä-Suomi käsittää Ahvenanmaan ja 15 eteläisintä metsälautakuntaa, joihin kuuluvat myös Pohjois-Karjala ja Pohjois-Savo.)

Puulaji	Tukkipuu	Kuitupuu	Yhteensä
Rauduskoivu	15 828	36 877	52 705
Hieskoivu	11 193	96 731	107 924
Haapa	2 348	13 266	15 614
Tervaleppä	245	3 362	3 607
Harmaaleppä	69	11 457	11 526
Muu lehtipuu	67	3 713	3 780
Yhteensä	29 750	165 406	195 156

eri puulajien puuaineksessa sekä puunrungoilla kasvavat pahkat, jotka voidaan laskea puuntuotannon sivutuotteiksi. Visaisuutta esiintyy, koivun visaisuuden lisäksi, myös terva- ja harmaalepällä, tammella, männyllä sekä kuusella (Saarnijoki 1961). On huomattava, ettei kuusen ja männyn visa ole sama asia kuin mukuramuodostumat ko. puitten rungoissa, ns. mukuramännyt (Ahola 1952, Saarnijoki 1961). Soitinten valmistukseen soveltuvat puut voidaan laskea myös erikoispuiksi. Hyviä soitinpuita ovat vanhat hitaasti kasvaneet jättiläiskuuset, pihlajat, tervalepät, haavat, vaahterat ja koivut, joilla on hyvät soitinpuulle ominaiset ominaisuudet, mm. kumajavuus.

Erikoispuulajit ovat siis edellä mainitun perusteella puulajeja, jotka esiintyvät rajoitetusti luontaisen kasvualueensa ulkopuolella, omaavat pienen osuuden metsäpinta-alasta ja vuotuisesta kasvusta sekä ovat rakenteeltaan ja ominaisuuksiltaan poikkeavia. Erikoispuulajien lisäksi voidaan puhua erikoispuutavaralajeista, jotka voivat olla mitä puulajia tahansa, mutta lasketaan käyttötarkoituksen, erikoisten dimensioiden tai vähäisen käyttömäärän vuoksi erikoispuutavaralajiksi. Erikoispuutavaraa on käyttökohteen edellyttämiin mittoihin sahattu ja katkottu puutavara, kuten kaivospuut, laatikkolautapuut, rullapuut, pylväät, junttapaalut, ratapölkyt sekä egyptin parrut (Lakio 1953). Ko. puutavaralaji ei myöskään mahdollisesti sovellu nykyiseen puutavaraluokitteluun.

1.3 Tutkimuksen tavoitteet

Tässä tutkimuksessa selvitetään Suomessa vähemmän käytettyjen puulajien laatu- ja mittavaatimuksia ja niiden nykyistä ja potentiaalista käyttöä Savo-Karjalan alueella.

Tutkimustyössä perehdytään seuraavien erikoispuulajien käyttöön:

- laadukas mänty (*Pinus sylvestris*)
- laadukas kuusi (*Picea abies*)
- laadukas koivu (*Betula pendula* ja *B. pubescens*); visakoivu
- lehtikuusi (*Larix decidua* ja *L. sibirica*)
- leppä (*Alnus incana* ja *A. glutinosa*)
- haapa (*Populus tremula*)
- kataja (*Juniperus communis*)
- pihlaja (*Sorbus aucuparia*)
- saarni (*Fraxinus excelsior*)
- tammi (*Quercus robur*)
- vaahtera (*Acer platanoides*)
- lehmus (*Tilia cordata*)
- jalava (*Ulmus glabra* ja *U. laevis*)

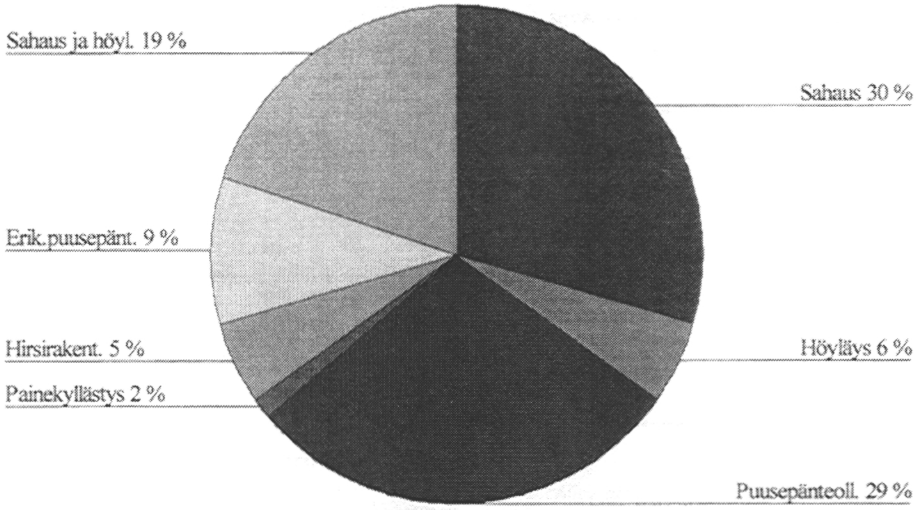
Tutkimuksen tavoitteet jakautuvat kahteen eri osaan:

1. Muodostetaan erikoispuutavaralajeille laatu- ja mittavaatimukset kyselyn perusteella.
2. Kartoitetaan erikoispuun nykyistä ja potentiaalista käyttöä Savo-Karjalan alueella.

Tutkimus on tehty Joensuun yliopiston sekä Metsämiesten Säätiön myöntämien apurahojen turvin. Professorit Pertti Harstela sekä Matti Kärkkäinen, lehtori Lauri Sikanen ja MH Pekka Huotari lukivat käsikirjoituksen ja tekivät siihen arvokkaita parannusehdotuksia. Esitän parhaat kiitokseni kaikille tutkimuksen valmistumiseen myötävaikuttaneille henkilöille ja organisaatioille.

2 Aineisto ja menetelmät

Tutkimuksen aineistona käytettiin helmikuussa 1994 kerättyä postikyselyaineistoa. Tutkittavien yritysten yritystiedot (toimiala, postiosoite) saatiin



Kuva 1. Yrityskyselyyn vastanneiden puuteollisuusyritysten toimialajakauma Savo-Karjalassa.

maakuntaliittojen ylläpitämästä teollisuusyritysrekisteristä. Tutkimuskohteena olivat kattavasti kaikki Pohjois-Karjalan ja Pohjois-Savon pyöreää puuta sahaavat sahayritykset (201 kpl). Lisäksi kysely lähetettiin osalle alueen puusepänyrityksistä (136 kpl). Nämä yritykset valittiin sillä perusteella, että ne käyttävät raaka-aineenaan pyöreää puuta, mutta eivät esimerkiksi levytuotteita. Myös alueella sijaitseville vaneritehtaille (2 kpl) lähetettiin kyselylomake, joilta todettiin, etteivät ko. tehtaat käytä tutkimuksen piiriin luettavia erikoipuutavaroita tuotannossaan.

Tehtyyn kyselyyn vastasi määräaikaan mennessä 52 yritystä. Kahden viikon kuluttua kyselyn lähettämisestä postitettiin karhukirje kaikille niille yrittäjille, jotka eivät olleet vielä vastanneet kyselyyn. Tämän jälkeen kyselyyn vastanneita yrityksiä oli 84 kappaletta, jolloin vastausprosentiksi muodostuu 25 %. Näistä yrityksistä 40 sijaitsee Pohjois-Karjalan läänin alueella ja 44 yritystä Kuopion läänin alueella. Vastanneiden puuteollisuusyritysten toimialajakauma koko Savo-Karjalan alueella jakautuu kuvan 1 mukaisesti.

Menetelminä tutkimuksessa on käytetty taulukointia sekä pääkomponenttianalyysia. Taulukointia on käytetty yksinkertaisten yhteenvetotaulukoiden luontiin, joista ilmenee nopeasti määrällisiä eroavaisuuksia. Monimuuttujamenetelmistä pääkomponenttianalyysia käytettiin aineiston analysointiin. Monimuuttujamenetelmään päädyttiin, koska haluttiin pelkistää monimutkaisen ja laajan aineiston tietoa.

Pääkomponenttien koostumusta selvitettäessä olivat periaatteet seuraavat: kertoimen suuri lukuarvo kertoo kyseisen muuttujan vaikuttaneen voimakkaasti pääkomponentin muodostukseen ja etumerkki kertoo vaikutuksen suunnan (Ranta ym. 1992). Analyysista saaduille komponenteille tehtiin vielä nk. Varimax-rotatointi, eli pyrittiin helpottamaan komponenttien tulkintaa niin, että muuttujien lataukset olivat joko selvästi pieniä tai suuria (Bühl 1994). Analyysin tuloksena saatujen pääkomponenttien koostumus selvitettiin ja annettiin komponenteille sanalliset kuvaukset.

3 Tulokset

3.1 Laatu- ja mittavaatimukset

Yrityksiä pyydettiin asettamaan laatu- ja mittavaatimuksia heitä kiinnostaville puulajeille. Laadukkaalle männylle, kuuselle ja koivulle asetetut mittavaatimukset eivät poikenneet merkittävästi jo käy-

Taulukko 4. Vastanneiden yrittäjien asettamia laatuvaatimuksia männylle, kuuselle ja koivulle

Laatuvaatimus	Osuus vastaajista % Mänty	Kuusi	Koivu
Oksaton tyvitukki	19	5	80
Vähäoksainen tukki	46	–	–
Normaalilaat. sahatukki	19	59	20
Välitukki	10	21	–
Heikompilaatuinen, ei tukkipuun mittoja täyttävä puuaines	6	15	–
Yhteensä	100	100	100

Taulukko 5. Vikaisuuksia puutavaralajeissa sallivien yritysten suhteellinen osuus.

Vika	Vikaisuuden sallineiden yritysten %-osuus Mänty	Kuusi	Koivu
Lievä lenkous	70	79	60
Laho	4	5	40
Oksakyhmyt	21	26	40

Taulukko 6. Yrittäjien asettamia laatu- ja mittavaatimuksia lehtikuuselle, haavalle ja lepälle.

Puulaji	Järeysaste (cm) Min	Max	Laatuvaatimus
Lehtikuusi	14	55	Normaalilaatuinen sahatukki
Haapa	14	–	Heikompilaatuinen sahatukki
Leppä	13	–	Heikompilaatuinen sahatukki

Taulukko 7. Vastanneiden yrittäjien asettamia pituusvaatimuksia haavalle ja lepälle.

Puulaji	Pituusvaatimus (m) Min	Max
Haapa	2,3	4,1
Leppä	2,5	5,2

tössä olevista. Sen sijaan käyttäjät asettivat taulukon 4 mukaisia laatuvaatimuksia ko. puulajeille.

Männyn kohdalla vähäoksainen tukki on halutuinta sahattavaa, kun taas kuuselle on menekkiä normaalilaatuisena sahatukkina. Koivun osalta yritykset ovat halukkaimpia ottamaan vastaan oksatonta tyvitukkia. Suhtautuminen lenkouteen, lahoon ja oksakyhmyihin on taulukon 5 mukaista.

Lievä lenkous sallittiin kahdessa kolmanneksessa yrityksistä joka puulajin kohdalla. Lahoa ei sallittu männyssä eikä kuusessa. Oksakyhmyt raaka-aineessa hyväksyy neljännes männyn ja kuusen jalostajista. Koivulla hyväksymisprosentti on suuri sekä lahon että oksakyhmyjen kohdalla.

Lehtikuuselle, lepälle ja haavalle asetettiin taulukon 6 mukaisia laatu- ja mittavaatimuksia.

Lehtikuuselle yrittäjät asettivat normaalin sahatukin laatuvaatimukset. Läpimittavaatimukset ovat hieman alhaisemmat kuin männyllä ja kuusella. Haapaa ja leppää yrittäjät hyväksyvät myös heikompilaatuisena tukkina, jonka vähimmäisläpimitaksi on asetettu haavalla 14 cm ja lepällä 13 cm.

Puutavaralajin pituudella ei yrittäjien mielestä ole suurta merkitystä lehtikuusen kohdalla. Sen sijaan haavalle ja lepälle asetettiin taulukon 7 mukaisia kriteerejä.

Haavalle ja lepälle asetetut pituusvaatimukset ovat samankaltaisia. Maksimipituudessa yrittäjät tahtoivat kautta linjan pitempää leppää kuin haapaa. Muutoin kriteerinä pidettiin yleisesti sahauskelpoisuutta. Lenkoutta sallittiin kaikissa kolmessa puulajissa, mutta lahoa ei sallittu missään muodossa muutamaa yrittäjää lukuun ottamatta. Oksakyhmyjä ei pidetty toivottavina lehtikuusessa; lepän ja haavan kohdalla oksakyhmyjä sallineiden osuus oli puolet vastanneista.

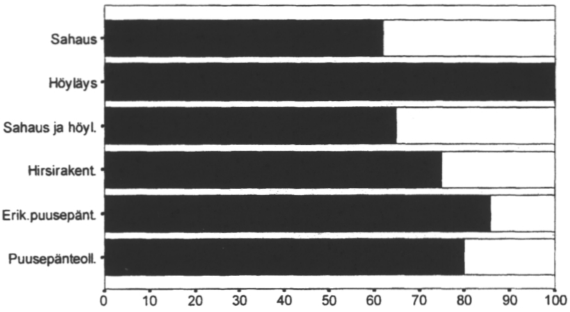
Visakoivulle ja katajalle ei asetettu vaatimuksia läpimitan eikä pituuden suhteen, vaan haluttiin raaka-ainetta rankoina sekä haarapölkkyinä. Pihlajaa haluttiin hitaasti kasvaneina tyvipölkkyinä (pituus 50–200 cm).

3.2 Erikoispuun käyttö

Taulukosta 8 ilmenee, että harvinaisempien puulajien käyttö on melko vähäistä määrällisesti, mut-

Taulukko 8. Harvinaisempien puulajien käyttö Savo-Karjalassa sekä arvio tarpeesta tulevaisuudessa. Taulukon käyttömäärät on saatu 23 yrityksen vastausten summana. Mukana ei ole polttopuukäyttöä.

Puulaji	Käyttö tällä hetkellä (m³/v)	Arvioitu tarve (m³/v)
Visakoivu	2	Muutamia kuutiometrejä
Haapa	199	5 500
Leppä	297	5 000
Lehtikuusi	108	3 180
Kataja	4	Muutamia kuutiometrejä
Pihlaja	7,5	Muutamia kymmeniä kuutiometrejä
Jalot lehtipuut	15	Muutamia kymmeniä kuutiometrejä
Yhteensä (m³/v)	632,5	Alle 14 000
Käyttömäärä / yritys (m³/v)	27,5	600



Kuva 2. Eri puuteollisuusyritystyyppien kiinnostus erikoispuulajien käyttöön. Kiinnostus: ■ kyllä, □ ei.

Taulukko 9. Rotatoitu pääkomponenttimalli yrityskyselyn muuttujista.

Muuttuja	K1	K2	K3	K4	K5
Aloitus	*	0,71	*	*	*
Hankin1	–*	–*	0,46	–*	–0,49
Kaytluo	0,84	–*	*	*	*
Kiinnost	*	0,62	*	*	*
Kuivaus	–0,42	–*	*	–0,63	*
Luok1	0,92	–*	*	–*	–*
Maara	*	*	0,30	0,36	*
Markkina	*	–*	–*	0,66	*
Paapl	–*	0,40	–*	0,37	–*
Paatuote	–*	–*	*	0,54	–0,38
Suunnitt	–*	0,68	0,32	*	–0,29
Tarpeell	*	*	*	*	0,45
Tietone	*	–*	0,51	–*	*
Ominaisarvot	2,38	1,99	1,54	1,36	1,18
Rotatoitujen komponenttien selitysaste (%)					
	20,0	10,3	9,4	8,6	7,4

aloitus = halukkuus aloittaa erikoispuutuotanto
hankin1 = raaka-aineen hankintatapa nyt
kaytluok = puun kokonaiskäyttö (m³/v)
kiinnost = kiinnostus laajentaa erikoispuulajeihin
kuivaus = tuotteen kuivaus
luok1 = henkilökunnan määrä
maara = arvio tarvittavasta erikoispuulajin määrästä (m³/v)
markkina = markkinoita erikoispuutuotteille
paapl = yrityksen käyttämä pääpuulaji
paatuote = yrityksen päätuote
suunnitt = muutoksia suunnitteilla tuotantoon
tarpeell = erikoispuulajien käytön lisäykseen ja tuotekehitykseen tähtäävien projektien tarpeellisuus
tietone = tietoinen Erikoispuupörssistä

ta ainakin kyselyyn vastanneiden yrittäjien osalta harvinaisempia puulajeja käyttää yllättävän moni yrittäjä eli melkein joka kolmas. Erikoispuulajeja, etenkin haapaa, leppää ja lehtikuusta, haluttaisiin käyttää huomattavasti enemmän, jos niitä vain olisi saatavissa. Kotimaista pihlajaa käytetään alueen pienyrityksissä 7,5 m³, kun Lounan ja Valkosen (1995) tutkimuksessa koko Suomen käytöksi on arvioitu muutamia kymmeniä kuutiometrejä.

Suurin kiinnostus erikoispuulajien käyttöön on höyläystä suorittavilla sekä käyttö- ja koriste-esineitä ja puusepänteollisuuden tuotteita valmistavilla yrityksillä (kuva 2). Osa näistä yrityksistä käyttää jo tällä hetkellä huomattavia määriä erikoispuuta tuotannossaan ja usea yritys olisi valmis lisäämään käyttöä, jos raaka-ainetta olisi paremmin saatavilla. Sahausta harjoittavista yrityksistä kaksi kolmesta on kiinnostunut erikoispuun tarjoamista mahdollisuuksista.

Pääkomponenttianalyysilla analysoitiin, mitkä tekijät olivat yrittäjän mielestä ratkaisevia tekijöitä, kynnyskysymyksiä, lisättäessä tai aloitettaessa erikoispuun käyttöä. Analysoinnissa käytettiin muuttujina kolmeatoista erilaista yritystä, sen puunkäyttöä ja erikoispuunkäytön mahdollisuuksia kuvaavaa tekijää. Mallilla kyetään selittämään 56 % aineiston kokonaisvarianssista (taulukko 9).

Tuloksena pääkomponenttianalyysista saatiin yksi koko tutkimuspopulaatiota selittävä komponentti (K1), jonka selittävyys on suuri, 20 prosenttia. Neljä muuta komponenttia selittävät tietyntyyppistä yrittäjää ja tekijää, joka on ratkaiseva erikoispuun käytön aloituksessa tai käytön lisäämisessä. Komponentit ovat seuraavat:

K 2: *(Uusi tuotantomahdollisuus)* Yrittäjä, joka on olosuhteiden vuoksi pakotettu suunnittelemaan muutoksia yrityksessään. Tämä lisää kiinnostusta erikoispuulajien käyttöön uutena tuotantomahdollisuutena.

K 3: *(Erikoispuun hankinta)* Yrittäjällä on jo tietoa erikoispuun käytöstä ja yritys saattaa käyttää erikoispuulajeja jalostuksessaan. Erikoispuunhankinta nousee vahvistuvasti esille komponentin vahvistuessa, eli yrittäjälle erikoispuun saatavuus on yksi avainkysymyksistä.

K 4: *(Markkinat)* Yrittäjätyypille markkinoiden olemassaolo ennen tuotannon aloittamista on tärkeää.

K 5: *(Kehittämisprojektit)* Erikoispuunkäytön kehittäminen nousee voimakkaasti esille. Yrittäjätyyppi on halukas kehittämään erikoispuun käyttöä, mutta muutoksia yrityksessä ei kuitenkaan ole suunnitteilla.

Seuraavassa taulukossa (taulukko 10) on esitetty erikoispuulajien kiinnostavuus yrityskoon mukaan tarkasteltuna.

Kiinnostuneimpia laajentamaan tuotantoaan erikoispuulajeihin ja myöskin aloittamaan sen ovat pienyritykset. Kaikkiaan 70 % yrityksistä on kiinnostunut laajentamaan tuotevalikoimaansa erikoispuihin. Kiinnostus laskee selvästi siirryttäessä suuriin yrityksiin, mutta osa niistäkin on kiinnostunut erikoispuulajeista, lähinnä lehtikuusesta. Taulukossa 11 on esitetty yrittäjiä kiinnostavat puulajit.

Selvästi yrittäjiä kiinnostavimmat puulajit ovat haapa ja leppä; näistä puulajeista on kiinnostunut yli puolet kaikista yrittäjistä. Laadukas mänty ja koivu sekä lehtikuusi muodostavat toisen selkeän ryhmän, joista yrittäjät ovat kiinnostuneet. Sen sijaan laadukas kuusi, visakoivu, kataja, pihlaja sekä jalot lehtipuut eivät kiinnostaneet kuin muutamaa prosenttia vastanneista yrittäjistä. Tarvitun erikoispuun määrä on noin 1000 m^3 vuodessa yritystä kohti, joka on huomattava ottaen huomioon yritysten tämänhetkisen kapasiteetin.

Yrittäjiltä kysyttiin, uskovatko he löytyvän markkinoita edellä mainituille erikoispuutuotteille. 29 %:lta yrittäjistä oli kyselty jotakin erikoispuutuotetta sekä 4 %:lla vastanneista yrityksistä oli jo sopimus asiakkaan kanssa jostakin erikoispuutuotteesta. Kysytyimpiä tuotteita ovat olleet leppäpaneeli (14 yritystä) sekä haapainen laudepuu (11 yritystä). Kysymykseen, kuinka haluaisitte kehittää erikoispuun hankintaanne, vastattiin taulukon 12 mukaisesti.

Neljännes kyselyyn vastanneista yrittäjistä hankkii puunsa omana hankintana. Toinen merkittävä hankintatapa on metsänomistajien suoraan yrittäjälle toimittama puu. Muita hankintatapoja tällä hetkellä ovat hankinta suuremman puunhankkijan kautta sekä verkostotoiminta yritysten kesken. Joka kymmenes yrittäjä hankkii puunsa puupörssin kautta.

Tulevaisuudessa puuta haluttaisiin hankkia pääasiassa omana hankintana sekä metsänomistajien

Taulukko 10. Kyselyyn vastanneiden yritysten myönteisten vastausten %-osuudet puun käyttömäärän mukaisesti luokiteltuna kysyttäessä kiinnostusta erikoispuun tuotantoon.

Puun käyttömäärä (m^3/v)	Kiinnostunut laajentamaan, %	Valmis aloittamaan, %
Alle 100	74	70
101–1 000	73	69
1 001–10 000	78	83
10 001–100 000	50	50
Yli 100 000	33	66

Taulukko 11. Kaikkia vastanneita yrittäjiä kiinnostavat erikoispuulajit sekä 22 yrittäjän arviot tarvitsemastaan erikoispuun määrästä (pyöreä puu).

Puulaji	Osuus vastaajista %	Määrä (m^3/v)
Laadukas mänty	14	4 715
Laadukas kuusi	2	2 000
Laadukas koivu	12	1 500
Visakoivu	2	–
Lehtikuusi	10	3 180
Leppä	29	5 000
Haapa	25	5 500
Kataja	2	–
Pihlaja	2	–
Jalot lehtipuut	2	–
Yhteensä	100	21 895

Taulukko 12. Kyselyyn vastanneiden yritysten nykyiset puunhankintatavat ja kiinnostus kehittää erikoispuun hankintaa tulevaisuudessa.

Hankintatapa	Haluaisin kehittää (%)	Hankin nyt (%)
Omana hankintana	24	25
Metsänomistajien suoraan toimittamana	21	22
Ns. kyläterminaalien kautta	3	–
Suuremman puunhankkijan kautta	6	14
Toimimalla verkostona muiden yritysten kanssa	6	17
Puupörssin välityksellä	12	8
Kaikki em. tavat	28	8
Pienet puunhankintafirmat	–	3
Kokonaishankintaketju	–	3
Yhteensä	100	100

Taulukko 13. Erikoispuutavaralajeille asetettavat vähimmäisläpimitta- ja pituusvaatimukset.

Puulaji	Vähimmäislpm (cm)			Vähimmäispituus (m)		
Laatuluokka	A	B	C	A	B	C
Lehtikuusi	25	14	8	2,40	2,00	2,00
Lehtipuut	20	14	8	2,40	2,40	2,00

suoraan toimittamana. Puupörssin välityksellä haluaisi puukauppansa hoitaa joka kymmenes yrittäjä. Toisaalta kolmannes yrittäjistä on valmis käyttämään mitä tahansa toimivaa puunhankintatapaa.

3.3 Laatuluokat

Laatu- ja mittavaatimukset lehtikuuselle sekä lehtipuulajeille (haapa, leppä, pihlaja, saarni, tammi, vaahtera, lehmus, jalava) muodostettiin yrityskyselyn perusteella. Sen sijaan laadukkaan männyn, kuusen ja koivun laatu- ja mittavaatimukset noudattavat jo nykyisiä käytössä olevia vaatimuksia. Visakoivulle sekä katajalle ei aseteta tämän tutkimuksen perusteella vaatimuksia läpimitan eikä pituuden suhteen, vaan oletetaan raaka-aineen olevan jalostettavissa olevaa puuta (rangat ja haarapölkyt). Pihlajan tyvipölkkyjen vähimmäispituusvaatimus on 50 cm.

Yrityskyselyn tuloksena esitetään kolmiluokkaista laatu- ja mittavaatimusluokittelua (taulukko 13).

Laatuluokka a
Tervettä puuta, jolla on erinomaiset puulajille ominaiset ominaisuudet. Puuaine tervettä, oksatonta tai melkein oksatonta ja suoraa. Puuaines saa omata merkityksettömiä vikoja, jotka eivät haittaa puun jalostamista ja käyttöä. Käyttö pääasiassa huonekalupuuksi, sorvattavaksi tai laadukkaaksi puusepänpuuksi.

Laatuluokka b
Normaalilaatuista puuta, jonka puuaineessa on seuraavia vikaisuuksia yksi tai useampia:

- lievää lenkoutta
- terveitä oksia, läpimitaltaan pieniä tai keskikokoisia
- vähäinen määrä pieniläpimittaisia kuivia oksia
- lievästi epämuotoinen runko

Käyttötarkoitus yleensä sahatuksi puutavaraksi, paneeliksi tai käyttöesineisiin.

Laatuluokka c
Puu, joka ei vikaisuutensa takia kelpaa laatuluokkiin A tai B. Puu on kuitenkin suurimmaksi osaksi teollisesti käytettävissä. Rungossa ja puuaineessa esiintyy seuraavia vikoja:

- voimakasta lenkoutta
- haaraisuutta ja voimakkaita poikaoksia
- värivikoja
- oleellisia hyönteisvahinkoja

Puun pääasiallinen käyttötarkoitus on käyttö- ja koriste-esineiden valmistus.

4 Tulosten tarkastelu

Yrityskyselyn perusteella on suhtautuminen erikoispuun käyttöön Savo-Karjalan alueella positiivisen kiinnostunutta. Negatiivista palautetta kyselyyn ei tullut, vaikkakin vastausprosentti jäi alhaiseksi.

Kyselyn perusteella kiinnostus erikoispuulajien jalostukseen on vastanneiden yrittäjien keskuudessa voimakas, sillä 70 % vastanneista yrityksistä on kiinnostunut laajentamaan tuotevalikoimaansa erikoispuutuotteisiin. Osittainen selitys suhteellisesti suureen kiinnostuneiden määrään lienee se, että yrittäjät, jotka eivät ole erikoispuun käytöstä kiinnostuneita, eivät vastanneet yhtä innokkaasti kyselyyn. Näin ollen kiinnostuneiden prosenttiosuus muodostuu suureksi. Jos oletetaan, että kyselyyn vastasivat kaikki erikoispuun käytöstä kiinnostuneet yrittäjät Savo-Karjalan alueella, muodostuu koko populaation estimaatiksi 18 % (vastausprosentti 0.25 × kiinnostusprosentti kyselyssä 0.70). Eli tämän mukaan noin joka viides Savo-Karjalan alueen saha- ja puusepänyrityksistä olisi kiinnostunut laajentamaan tuotevalikoimaansa erikoispuutuotteisiin. Todellinen kiinnostuneiden prosenttiluku löytynee näiden ääripäiden välistä.

Ylivoimaisesti kiinnostavimmat puulajit ovat leppä sekä haapa. Osa yrittäjistä on kiinnostunut jalostamaan laadukasta mäntyä ja koivua sekä lehtikuusta. Kiinnostus jalojen lehtipuiden jalostamiseen on hyvin vähäinen.

Kyselyyn vastanneet yritykset hankkivat puunsa tällä hetkellä omana hankintanaan tai metsänomistajan suoraan toimittamana. Samalta pohjalta halutaan puunhankintaa kehittää myös jatkossa. Puupörssin kautta haluaa toimintaansa kehittää 12 % puunjalostajista sekä lisäksi ne yrittäjät (28 %), jotka ovat kiinnostuneet mistä tahansa toimivasta puunhankintasysteemistä.

Koko tutkimusaineiston kattavalla pääkomponenttianalyysilla haettiin tekijöitä, jotka ratkaisevat yrittäjien halukkuuden käyttää erikoispuuta raaka-aineenaan. Analyysin tuloksena saatiin yksi koko tutkimuspopulaation käyttäytymistä kuvaava komponentti ja neljä erilaisia tekijöitä kuvaavia komponentteja (uusi tuotantomahdollisuus, erikoispuunhankinta, markkinat, kehittämisprojektit).

Osa yrittäjistä pitää erikoispuunjalostusta *uutena tuotantomahdollisuutena*. Erikoispuun jalostuksesta saatetaan hakea tasoittajaa ja tuotannon monipuolistajaa suhdanteiden vaihdellessa.

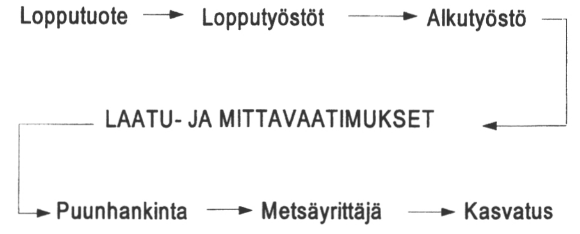
Erikoispuunhankinta nousee tuotannon alkaessa tai sitä lisättäessä ongelmaksi. Tähän vaikuttanee erikoispuun epävarma saatavuus, epätietoisuus laatu- ja mittavaatimuksista sekä mahdollisesti tuotantoon tarvittavan raaka-aineen pienet ja vaikeasti ennakoitavat määrät. Vakiintumaton erikoispuiden ostohintataso on myös omiaan kärjistämään erikoispuunhankinnan ongelmia. Tässä nousevat esille myös erilaiset vaihtoehtoiset hankintamuodot (puupörssi, yritysverkostojen kautta hankittava puu), joihin kyselyn perusteella on kohtalaista kiinnostusta.

Erikoispuujalosteille löytyvät *markkinat* ovat analyysin mukaan yksi merkittävä tekijä. Kyselyssä kävi ilmi, että kolmannekselta yrittäjistä oli kyselty erikoispuutuotteita. Tilanteeseen saattaa vaikuttaa vielä se, että sahaajat ja sahatavaran käyttäjät eivät välttämättä kohtaa toisiaan markkinoilla, eivätkä tiedä toistensa tarpeista.

Analyysin neljäs komponentti toi esiin *kehittämisprojektit*, joita kaivataan erikoispuun käytön edistämiseksi (koulutus, neuvonta, konsultointi). Tämä tarkoittaa logistista ketjua alkaen aina asiakkaan tarpeista jatkuen tuotekehitykseen, tuotantoon, varastointiin ja kuljetukseen sekä sivutuotteiden käsittelyyn. Tähän liittyen erikoispuulajien pätevät laatu- ja mittavaatimukset ovat ensisijaisen tärkeät (Erikoispuiden käytön lisäämisprojektiin ..., 1995).

Kuten taulukosta 6 kävi ilmi, kyselyyn vastanneet yrittäjät ovat esittäneet mittavaatimuksensa lehtikuusen, haavan ja lepän osalla normaalilaatuiselle tai sitä heikompilaatuiselle puuainekselle ja rungolle. Muutamat olemassa olevat lähteet tukevat osaltaan tutkimustuloksia. Verkasalon (1993a) tutkimus tukee yrittäjien asettamia mittavaatimuksia lehtikuusen osalla; samoin Lounan ja Valkosen (1995) tutkimuksessa lehtipuille asetetut mittavaatimukset ovat yrittäjien lehtipuille asettamien vaatimusten kanssa yhteneviä. Keinäsen ja Tahvanaisen (1995) Pohjolan Jalot Puut -opas sen sijaan antaa minimiläpimittojen osalta huomattavasti poikkeavia arvoja. Sama on huomattavissa pituusvaatimuksissa lehtikuuselle ja haavalle; muille puulajeille pituusvaatimukset ovat samaa luokkaa.

Kuvassa 3 on esitetty logistinen ketju erikoispuun laatu- ja mittavaatimusten määrittämisestä. Käyttäjä-orientoituneessa mallissa on lähtökohtana määrittää laatu- ja mittavaatimukset loppukäyttötasolta. Kuluttajan (lopullisen asiakkaan tai jatkojalostajan) mieltymykset ja tarpeet ohjaavat voimakkaasti tarvittavalle raaka-aineelle asetettuja kriteerejä. Kuluttajan (lopputuote) vaatimuksia ohjaa-



Kuva 3. Käyttäjä-orientoitunut malli erikoispuun laatuvaatimusten määrittämisestä.

vat esimerkiksi uudet toteuttamiskelpoiset ideat ja trendit suunnittelussa. Näin syntyneen kysynnän kautta ohjataan puun jatkojalostajia (lopputyöstöt), jotka haluavat tarjota kuluttajilleen oikeanlaista tavaraa ja vaativat sitä myös sahayrityksiltä (alkutyöstö).

Ketju etenee puunhankintaan, jonka kautta on hankittava sopivaa raaka-ainetta jalostukseen. Mahdollisia hankintamuotoja erikoispuun osalla ovat puupörssi, terminaalikauppa, metsäpalveluyrittäjät sekä normaalit hankinta- ja pystykaupat sekä käteiskaupat. Tässä vaiheessa on oltava tiedossa yhteiset laatu- ja mittakriteerit, joiden mukaisesti puu voidaan apteerata. Sopivan erikoispuun kasvatus on metsäyrittäjän harteilla, joka viime kädessä pystyy vaikuttamaan huomattavasti optimaalisen raaka-aineen tuottamiseen.

Kaikkiaan erikoispuun kohdalla sekä puun kysyntä että tarjonta on vielä melko vähäistä. Tärkeää on kuitenkin, että viesti erikoispuun käytöstä ja markkinoiden mahdollisuuksista saadaan liikkeelle. Toimiva erikoispuutavaran hankintasysteemi sekä jokapäiväiseen käyttöön saadut laatu- ja mittavaatimukset ovat parhaita keinoja saada erikoispuulajien hankintakustannukset kilpailukykyiselle tasolle. Tällöin on luotu toimintamahdollisuudet järkevälle erikoispuuta jalostavalle pienteollisuudelle.

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47 viitettä

II

SPECIES, FURNITURE TYPE, AND MARKET FACTORS INFLUENCING FURNITURE SALES IN SOUTHERN GERMANY

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ABSTRACT

The aim of this study was to investigate the furniture markets in Central Europe as a case study focusing on the economic area of Munich, southern Germany. The topics studied were the breakdown by tree species and furniture types and the marketing factors used to differentiate the product or the sales approach. The factors were divided into 19 different classes, which were classified empirically during the study: price, design, tree species, furniture selection, domestic product, general quality, durability of materials, „green attributes", extra equipment, delivery in pieces, new products, finishing (waxed and oiled), waxing, oiling, stable construction, guarantee, material, comfort, and practicality. Data were collected from the advertisements in provincial and local newspapers and from advertisements distributed by furniture stores.

The most important marketing factor was design (28.2 %), which was almost 10 percentage points more than for the second most important factor, species (18.7 %). Price was ranked third (14.9 %). „Green attributes" and finishing (waxed and oiled), which are ecological factors, were ranked fifth and seventh. „Green attributes" were even more common among the marketing factors than the concept of quality. According to this study, there are large differences in the marketing of wood furniture in different European countries, e.g. Finland and Germany. In Finland, furniture is marketed as good value for the money, large selection, and domestically produced. In Germany, design, species and pro-environmental factors are highlighted. When „green attributes" and species are used in advertising, pro-environmental thinking is being emphasized.

P&P Statement: The results of this study highlight the use of different species in the German furniture markets and the pro-environmental thinking of furniture advertising. This information has practical importance for furniture manufacturers and exporters.

SPECIES, FURNITURE TYPE, AND MARKET FACTORS INFLUENCING FURNITURE SALES IN SOUTHERN GERMANY

INTRODUCTION

Furniture plays an important role in satisfying the social needs of the family. For example, there are differences among family members in their use of the living-room; the children of the family may use it very little (when not watching TV) and adult use is mostly in the evenings and on weekends. Home is not only a physical state but it also includes the net of social relations for family members, friends, and neighbors. Home also indicates the identity of the person, reflecting his or her life style and personal values. People do not want a home that is too perfect, but rather a home of the style which can be changed when the demands of the owner change. Furniture represents the changeable part of the home, and with its help the individual is able to express his / her personality and feelings. Moreover, through furniture the family can also express their social status. Furniture is commonly associated with memories and experiences of childhood, as most people remember the furniture in their childhood home. In general, furniture plays a very stable and essential role in our lives; and of the objects in a home, for most people, furniture is the most important (18).

When the concept of „furniture“ is considered, the importance of style and fashion must be clarified. According to Trankle (31), style is understood to be longer lasting than fashion. Furniture can also be seen as a status symbol. The furniture style symbolizes the „style“ and the living standards of the family. The importance of a living room is even greater because most of the social communication with guests takes place there.

The consumer‘s behavior in marketing situations has been investigated in many studies (4, 6, 8, 12, 15, 17, 19, 20, 23-26, 29, 32, 33). In Schreiber‘s study (26), five criteria are listed that must be taken into consideration when the buying behavior of a consumer is studied: 1) price-consciousness, 2) quality-consciousness, 3) original, unusual decision, 4) planned decision; and 5) nonconformist decision. On the one hand, the price-consciousness of the consumer varies according to how urgently he / she needs the product. On the other hand, discounts in prices very obviously affect customers positively. One factor in the buying process is that consumers may have chosen in advance the style they are looking for (e.g., Scandinavian style). This reduces the need to sort through many sources of information and markets already in the beginning of the search. Another factor is the style of the consumer‘s previous furniture. Households that were satisfied with their old furniture need a shorter time for consideration and they simplify their decision making by considering fewer alternatives than those households that were not satisfied with their old furniture.

In the buying process, the wife plays an important role because it is usually she who provides the impetus to change the furniture. The husband has a greater influence on the price group of the furniture and the wife on factors such as style, product name, and store (5, 27). Despite these differences, most buying decisions are made jointly. The children also have an important role in buying furniture; according Bücker‘s study (4), in most cases (66 %) the opinions of children are asked when furniture is bought for the living room. It was also shown that buyers with higher education and better incomes use more sources of information when buying furniture.

The choice of furniture store from the standpoint of price has been investigated in two studies (7, 13). Other relevant factors are product aspects (quality, variation of assortments) and convenience of shopping (location, parking possibilities, client information, etc.). Different payment possibilities (installment, loan, cash discount) may also influence the buying decision. Other aspects affecting furniture purchases are material, form, color, standards, and certificates. Already at the beginning of their search, consumers have problems deciding which information sources they will use in the decision process. Sources of information about furniture available for sale are furniture magazines, ads, shop windows, etc. These are considered in **Fig. 1**.

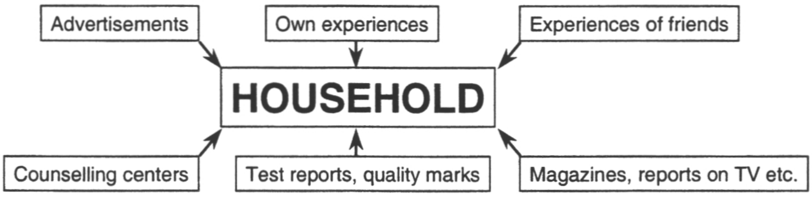

Figure 1. — The household in the information field (22).

The basics in marketing and advertising research have been reported in several studies (16, 22, 28). The interpretation of advertising has also been investigated in many studies (1, 2, 3, 9, 10, 17). In order to study green advertising, Soikkeli (30) explored furniture ads from decorating magazines. Haiminen (14) concluded that, in general, green marketing ads are honest and relevant; but they transmit too little environmental information. Altogether, ad studies are rarely used in investigating forest product markets. Therefore, the aim of the present research was to investigate the furniture markets in Central Europe as a case study, focusing on the economic area of Munich, and to determine how these markets are influenced by species, furniture type, and marketing factors, i.e. how the products are sold.

MATERIAL AND METHODS

The material used in this study consisted of ads collected in southern Germany in the economic area of Munich (6 Mill. inhabitants). Data were collected from ads in provincial and local newspapers and from the ads of furniture stores. Two newspapers were checked systematically (Tageszeitung München TZ and Freisinger Kreisbote). Ads were collected from 24 different furniture stores, including both small and large firms. Data were collected during the period from week 40/1997 until week 40/1998 and the ads were collected every second week.

Marketing factors were divided into 19 different classes, which were classified empirically during the study: price, design, species, selection, domestic product, quality, durability of the materials, „green attributes", extra equipment, delivery in pieces, new product, finishing (waxed and oiled), waxing, oiling, stable construction, guarantee, material, comfort, and practicality. For example, „green attributes" meant that the concept „pro-environment" was highlighted. In the advertisement, it could be said that the timber used in the furniture came from sustainably managed forests.

The data comprised 3246 pieces of furniture, of which 2347 were wooden. The furniture was divided into four main types: solid wood, partly solid wood, composite, and upholstered furniture. In this study, furniture that was to any extent upholstered was not included in the solid wood furniture category, even if the construction of the furniture frame was solid wood. Instead, this kind of furniture was considered to be upholstered furniture, which is not considered in this article **(Table 1)**. Composite furniture is a piece of furniture that is built from composite panels that are overlaid with veneers or printed-grain plastic materials. The data were analyzed by cross-tabulation. In order to study the marketing factors used for different types of structure, a Chi-Square-Test was also used, but no significant difference was found. This was an expected result while it is supposed that certain arguments, like price, have a greater significance in solid and plate-structured furniture than in partly solid.

TABLE 1. — *Summary of the key characteristics of the material studied.*

Characteristics	Frequency	Percentage (n = 2347)	Furniture	Frequency	Percentage (n = 2347)
Type of magazine					
Provincial newsp.	15	0.7	Wardrobe	524	22.3
Local newsp.	9	0.4	Secretary	339	14.4
Advertisement	2323	98.9	Bookshelf	203	8.6
			Chair	183	7.8
Type of store			Coffee table	143	6.1
Chainstore	370	15.8	Dining table	132	5.6
Local	1977	84.2	Bed	128	5.5
			Writing table	109	4.6
Type of furniture			Bedroom furn.	98	4.2
Solid	1133	48.3	Kitchen furn.	89	3.8
Partly solid	468	19.9	TV-table	72	3.1
Composite	746	31.8	Shelf	70	3.0
			Glass cabinet	62	2.6
Use					
Outdoor	142	6.1	Glass cabinet / closet	38	1.6
Indoor	2205	93.9	Garden table	36	1.5
			Table group	33	1.4
			Bench	32	1.4
			Bedside table	31	1.3
			Trunk	11	0.5
			Couch	8	0.4
			Couch group	3	0.3
			Rocking chair	2	0.1

Almost all ads were obtained from free advertisement material delivered by mail. In the newspapers, there were few ads to analyze. The furniture stores were categorized as large chain stores or local companies. More than 80 percent of the furniture ads were from firms that operated locally. Large multinational furniture companies were intentionally omitted while only the market situation in the southern Germany was studied. Almost half of the furniture was made from solid wood and 20 percent was partly solid. More than 30 percent of the furniture was composite.

Smaller, environmentally oriented („green") firms clearly specialized in certain types of advertisements. This difference was not only obvious in terms of the number of furniture pieces advertised but also in the marketing arguments used to sell them; e.g., the ads of environmentally oriented firms differed considerably from those of the larger firms. The larger firms attempted to fill out their ads with colors and numbers, while the ads of „green" firms were more subdued. In these latter ads, there were nature photos, the text was restrained, and the prices were given inconspicuously. For the same size of ad paper, „green" firms had fewer items than the larger companies did. The ads of environmentally oriented firms were easy to read, and the appearance of the ad demonstrated what kind of product was for sale:

a close-to-nature and good-quality product. The good sense and feelings of the customer were appealed to in these ads.

In this study the furniture was divided into 22 categories. The largest groups were wardrobes (22.3 %) and secretaries (14.4 %). Groups like bookshelves, chairs, coffee tables, dining tables, beds and writing tables also exceeded 100 units. Bedroom sets (bed, wardrobe, and bedside table) and kitchen furniture sets (five kitchen cupboards without electrical equipment) were also included in the study.

RESULTS

TABLE 2. — *Summary of marketing factors and species.*

Marketing factor	Frequency	Percentage (n = 2347)	Tree species	Frequency	Percentage (n = 2039)
Design	661	28.2	Pine	675	33.1
Tree species	440	18.7	Beech	514	25.2
Price	350	14.9	Spruce	272	13.3
Practicality	235	10.0	Alder	203	10.0
„Green attributes“	169	7.2	Oak	118	5.8
			Maple	60	2.9
Quality	139	5.9	Birch	35	1.7
Finishing	115	4.8	Linden	26	1.3
Selection	63	2.7	Cherry	25	1.2
Extra equip.	58	2.5	Teak	25	1.2
Durability of materials	57	2.4	Ash	20	1.0
			Rattan	16	0.8
Stable constr.	20	0.9	Mahogany	12	0.6
Comfort	20	0.9	Walnut	11	0.5
New product	10	0.4	Root tree	10	0.5
Material	5	0.2	Acacia	10	0.5
Guarantee	5	0.2	Others	7	0.4

When all results were considered, design was the most frequently mentioned marketing factor **(Table 2)**. The proportion of the marketing arguments based on design was 28.2 %, which was almost 10 percentage points higher than for the second most important argument: species. Price was ranked third. Interestingly, „green attributes“ and finishing (waxed and oiled), which are ecological attributes, placed fifth and seventh. „Green attributes“ were even more common among the marketing factors than the concept of quality.

Pine dominated as a furniture species, making up one-third of the construction material. Beech took second place. The next two species, spruce and alder, lagged far behind. The proportions of tropical species like teak, mahogany, and acacia were very small.

TABLE 3. — *Origin of the furniture and colors used in painted furniture.*

Origin	Frequency	Percentage (n = 149)	Colour	Frequency	Percentage (n = 197)
Scandinavian	81	54.4	Beech	90	45.7
German	53	35.6	Pine	45	22.8
Other	15	10.0	Cherry	19	9.6
			Alder	14	7.1
			Chestnut	12	6.1
			Other	17	8.7

The origin of the furniture was also studied **(Table 3)**. In most of the ads, however, the origin of the furniture was not mentioned; in 149 ads the origin was given. According to this, the origin was mentioned as Scandinavian in half of the mentions of origin and German in one-third of them. Some of the solid wood furniture was painted a color that was intended to match that of a particular species. Beech was imitated in 90 cases and pine in 45 cases.

It should be noted that some of the composite pieces of furniture that were overlaid with plastic were lower in price. Of the 658 plate-structured pieces of furniture in this study, 51.7 percent were plastic overlaid **(Table 4)**.

TABLE 4. — *Number of composite furniture pieces, by species, percentage overlaid with wood veneer, and percentage overlaid with printed-grain plastic (n = 658).*

Species	No. of composite pieces	Percentage overlaid with wood veneer	Percentage overlaid with plastic
Beech	384	42.4	57.6
Alder	79	43.4	56.6
Maple	50	46.0	54.0
Oak	39	89.7	10.3
Ash	19	42.1	57.9
Birch	11	54.5	45.5
Cherry	11	90.7	9.1
Walnut	11	0	100
Root tree	10	0	100
Other	44	66.7	33.3

The proportion of composite furniture overlaid with printed-grain plastic was about the same in the three largest groups of species (beech, alder, and maple). For some species, such as oak and cherry, the proportion was much lower due to the fact that oak and cherry are considered expensive species for furniture and they are seldom imitated.

TABLE 5. — *Distribution of furniture by species and type (n = 2039).*

Tree species	Total	Solid	Partly solid	Plate structured
Pine	675	85.6	13.0	1.4
Beech	514	4.5	20.8	74.7
Spruce	272	68.4	31.3	0.3
Alder	203	28.6	32.5	38.9
Oak	118	21.2	45.8	33.0
Maple	60	-	16.7	83.3
Birch	35	8.6	60.0	31.4
Linden	26	92.3	-	7.7
Cherry	25	56.0	-	44.0
Teak	25	100.0	-	-
Ash	20	-	5.0	95.0
Rattan	16	100.0	-	-
Mahogany	12	100.0	-	-
Walnut	11	-	-	100.0
Root tree	10	-	-	100.0
Acacia	10	100.0	-	-
Others	7	42.9	14.2	42.9

Table 5 shows that softwood furniture (pine and spruce) was most often solid wood. All tropical hardwood furniture (teak, mahogany, and acacia) was solid wood. Alder and oak had quite equal proportions of every structural type of furniture, but beech furniture was mostly composite and only occasionally solid. The use of different species by category, and prices according to category, type, and species are shown in **Tables 6 and 7**, respectively.

TABLE 6. — *Proportion (%) of furniture by species and category (n =1651).*

Tree species	Wardrobe	Secretary	Bookshelf	Chear	Coffee table	Dining table	Bed	Writing table
Pine	34.0	33.7	11.7	45.7	18.1	32.0	58.4	42.4
Beech	23.8	22.0	33.0	8.7	36.2	28.4	31.0	42.4
Spruce	22.0	16.3	6.1	7.8	8.5	6.6	1.8	8.6
Alder	9.8	8.9	19.8	2.4	18.1	10.7	6.2	1.1
Oak	2.9	5.2	6.6	7.0	6.1	11.5	-	1.1
Maple	1.2	5.8	6.6	1.6	1.1	1.6	1.8	3.3
Birch	1.2	1.8	5.6	-	1.1	-	-	-
Linden	0.6	1.5	-	-	6.4	1.6	-	-
Cherry	1.2	0.3	4.6	0.8	1.1	2.5	-	1.1
Teak	-	0.3	-	10.6	1.1	0.9	-	-
Ash	0.4	1.5	-	-	-	-	-	-
Rattan	-	-	-	10.6	-	-	0.9	-
Mahogany	0.6	-	1.0	2.4	1.1	0.9	-	-
Walnut	-	0.3	1.0	-	1.1	0.9	-	-
Root tree	-	0.3	1.0	-	-	1.5	-	-
Acacia	0.2	0.9	-	2.4	-	0.9	-	-
Others	2.1	1.2	3.0	-	-	-	-	
Total pcs	491	326	197	170	125	125	120	97

TABLE 7. — *Variation in furniture prices (DEM)[a] according to category, type, and species.*

Type of	Solid					Partly solid					Composite				
furniture	Pine	Spruce	Alder	Oak	Linden	Beech	Spruce	Pine	Alder	Oak	Beech	Alder	Maple	Oak	Ash
Wardrobe	1405	1386	2067	4157	898	815	829	902	1073	1399	679	726	1110	1238	279
Mean	1459					974					705				
Secretary	715	776	722	1537	1078	693	514	620	700	430	314	171	588	299	101
Mean	747					657					354				
Bookshelf	2050	2903	5165	849	-	1942	610	1498	2465	2704	1557	676	1234	464	-
Mean	2700					2438					1524				
Chair	206	294	213	295	156	149	-	174	-	-	112	-	-	139	-
Mean	230					261					119				
Coffee table	550	360	781	998	494	270	-	598	249	49	164	128	-	301	-
Mean	633					331					193				
Bed	493	98	1249	-	-	678	275	564	-	-	609	445	775	-	-
Mean	512					734					579				
Mean species	889	1130	1229	1317	675	898	724	829	1408	1273	719	604	886	623	152
Mean total			1047					899					579		

[a] Deutsch mark

According to **Table 7,** the price relations between solid, partly solid, and composite furniture seem to be similar for all six categories of furniture. Solid-structured furniture was the most expensive, partly solid was in the middle price range, and composite was the least expensive. For chairs and beds, however, the average prices for partly solid furniture were even higher than for solid-structured. Moreover, softwoods were very obviously used only for solid and partly solid pieces of furniture, and hardwoods were the most commonly used species in composite furniture.

Certain price groups could be identified. On the whole, oak furniture was the most expensive price group, closely followed by alder. Furniture from beech had noticeably lower prices when made into partly solid furniture but considerably higher prices as composite pieces, compared to those from oak or alder. Pine and spruce furniture was the least expensive in solid and partly solid furniture. Composite maple and beech furniture was considerably more expensive than that from alder or oak.

DISCUSSION

The material in this study consisted mainly of the advertisement material for 24 furniture stores. The largest stores advertised all kinds of furniture equally.

Interestingly, the domestic origin of the furniture was not considered to be an advantage. Softwoods were sold as solid-structured furniture. The proportions of these species in composite furniture were marginal. The tropical hardwoods (teak, mahogany, and acacia) were sold only in solid-structured form. Another very obvious aspect was that the softwoods were used only for solid and partly solid pieces of furniture and hardwoods were the most common species in composite furniture. This is obviously a consequence of the price difference between hardwoods and softwoods, since the average import price for hardwoods was considered to be higher than that of softwoods (11).

According to this study, with regard to species, there were certain price groups of furniture. On the whole, oak furniture was the most expensive with alder following as a close second. Furniture from beech was noticeably less expensive when used as partly solid but considerably more expensive as composite furniture. Pine and spruce furniture was the least expensive in solid and partly solid furniture. Composite maple and beech furniture was considerably more expensive than that made from alder and oak.

The most important source of error in this material was the subjective sampling of the advertisements, even though all kinds of furniture stores were included in the material. Along with the geographical concentration of the sampled material (economic area of Munich), this permits only limited possibilities to apply the results elsewhere in Central Europe. Unfortunately, the furniture purchasers were not interviewed; interviews would have made possible detailed comparison between advertising arguments and purchaser requirements. Nevertheless, the material gives an indication of furniture advertising and markets in southern Germany.

When comparing the results to other European countries, e.g. Finland, the marketing of wood furniture differs greatly. In Finland, the furniture is marketed as good value for money, large selection, and domestically produced (22); in Germany, design of the furniture, species, and pro-environmental aspects are highlighted. The difference in marketing between Finland and Germany is even greater for solid wood furniture. When „green values“ and species are used in marketing, the advertiser wants to highlight pro-environmental thinking.

The results of this research on the use of different species by Central European furniture manufacturers is important to the Scandinavian wood processing industry because Central Europe represents their most important export markets. In Scandinavia, silviculture has traditionally focused mainly on three species: pine, spruce, and birch. This study clearly showed that in furniture markets, other species, like alder, are also popular. This raises interesting questions: What will be the future of the silviculture of alder ? Are there any economic possibilities in Scandinavian forestry to plant and manage alder?

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III

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Diameter distribution, stem volume and stem quality models for grey alder (*Alnus incana*) in eastern Finland

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Abstract. Stand-level predictions of basal-area diameter distributions, height, positions of lowest dead and live branches and stem-rot are provided for grey alder in eastern Finland. The usability of models was tested by calculating the accuracy of predicted volume characteristics. The data were collected from 33 stands situated in the provinces of North Karelia and North Savo in eastern Finland. These stands were regenerated naturally, but some have been managed. One to three angle-count sample plots were placed systematically in each stand using a 1 m^2 ha^{-1} basal-area factor. The models can be applied in two settings: tree diameters are either measured or not. The prediction of branch height characteristics, especially height to the lowest dead branch, proved problematic due to weak correlations between these characteristics and other tree dimensions. Compared to previous studies it was found that stem-rot was higher in grey alder than in spruce but lower than in white birch.

Introduction

During a period of shifting cultivation in the 18th and 19th centuries, grey alder (*Alnus incana*) spread throughout southern Finland. In silvicultural cuttings after World War II, alder gave way to other tree species and alder-dominated forests have since been on the decrease. The greatest concentration of grey alder is in eastern Finland where shifting cultivation continued longer. According to the Eighth National Forest Inventory of Finland, in the provinces of North Karelia and North Savo three percent of the volume of growing stock consists of grey alder (Metsätilastollinen vuosikirja 1996). Its proportion of the number of trees per hectare is as high as 17%; this is in contrast to the average of 9.6% for southern Finland.

Grey alder has been little used as a raw material for the forest industry. However, the importance of alder species has recently clearly increased. The increasing need for inexpensive energy has focused attention on renewable biomass resources. In Finland, researchers have suggested that the woody biomass produced by fast-growing deciduous species, such as grey alder to be used as an alternative to imported energy sources (Saarsalmi et al. 1985, 1991, 1992). Recently, alder has also become a realistic alternative for the reforestation of former agricultural areas. Alder species are actinorrhizal plants; they live in symbiosis with nitrogen-fixing actinomycetes (*Frankia* spp.). Therefore, they have the ability to increase the nitrogen content of the soil.

The profitability of growing grey alder depends also on its suitability as a raw material for industries. The wood is homogenous and easy to work with, making it suitable for various products and many special purposes, such as for making music instruments (Kärki 1997b). When considering the quality of grey alder, it has been found that dimensions, decay and knottiness are the most important factors influencing the value of sawn alder timber (Kärki 1997). According to Kärki (1999a), rot and discoloration in grey alder wood cause 13 percent of the decrease in the quality of individual pieces of lumber. In a living tree, rot normally begins from damage to the tree; damage can be caused by management operations, animals, and environmental damage such as storm breakage, which can initiate entry for fungal infection (Kallio 1972).

Information about grey alder resources in Finland is available mainly from the national forest inventories. This information is useful for large-scale estimates, but there is a lack of knowledge and models for predicting the amount and quality of alder in stands and forest holdings. The first growth and yield studies on grey alder were made before World War II by Miettinen (1933). However, when considering models, only taper curve have been estimated in Finnish conditions (Mäkinen 1984). This taper model concerns both grey and black alder and is applicable only for small trees. The mean tree diameter in Mäkinen (1984) was close to 4 cm and the largest diameter was nearly 15 cm.

In Finland, the actions of forest management planning are based on inventory by compartments, where only mean stand characteristics, such as mean diameter and height, basal area and age, are measured. Calculations of stand characteristics are then based on theoretical diameter distribution, tree height and taper models (Laasasenaho 1982; Veltheim 1987; Kilkki et al. 1989). Using this approach it is possible to determine stand volume quite precisely but the wood quality cannot be estimated. For example, the calculation of the amount of sawn timber is based only on tree dimensions and thus the amounts of different quality classes of sawn wood cannot be calculated.

There are several models which include height of the lowest living branch and lowest dead branch and stem rot characteristics for main tree species in Finland (Koivunen 1989; Mäkelä 1990; Rouvinen et al. 1997). In most cases these models include variables which are not normally measured as mean stand characteristics and cannot therefore be applied directly in forest management planning. In some recent studies it has been proposed that stem quality should be added to field measurements for forest management planning (Rouvinen et al. 1997).

In the study of Rouvinen et al. (1997), in addition to normal measurements of mean diameter and height, mean height of the lowest living branch and lowest dead branch were measured. Firstly, branch height characteristics were generalized to all trees of the stand using measured mean branch height characteristics to calibrate existing branch height models by stand. It was expected that these branch heights determine the timber quality classes between branchless logs, logs with dead branches and logs with living branches. Finally, these branch heights and tree taper were used in determining the optimal volumes of logs of these timber quality classes (Rouvinen et al. 1997; Puumalainen 1998).

The aim of this study was to estimate models of diameter distribution, stem volume and stem height for grey alder. These models allow us to derive forest level estimates for grey alder using mean stand characteristics. In addition, the characteristics needed to establish models describing tree quality characteristics were determined. Finally, various stand volume characteristics are calculated using the new models and independent tree measurements.

Material and methods

Data collection

The material in this study, included 33 stands (minimum area of 0.5 ha) situated in the provinces of North Karelia and North Savo in eastern Finland (Figure 1). The stands were naturally regenerated, but at least part of them have been under management. From one to three angle-count sample plots were located systematically in each stand depending on the size of the stand using a relascope with a basal area factor (BAF) of 1 m^2 ha^{-1}. A total of 75 sample plots were measured. Tree species and diameter of each tree were recorded. Stand age, stand basal area, forest site type, basal area median diameter, median and dominant heights were measured on the sample plots. Mean stand characteristics are shown in Table 1. The stand characteristics are the same as those used in conventional compartment level forest inventories. Tree height and height of the lowest living branch and lowest dead branch were measured on the shortest, tallest and median tree of each plot (Table 2). These sample trees, altogether 230, were felled and the diameter and bark thickness at relative heights of 1, 5, 10, 20, 30, 40, 50, 60, 70, 80 and 90% were measured. If rot was detected, the diameter at stump height and the

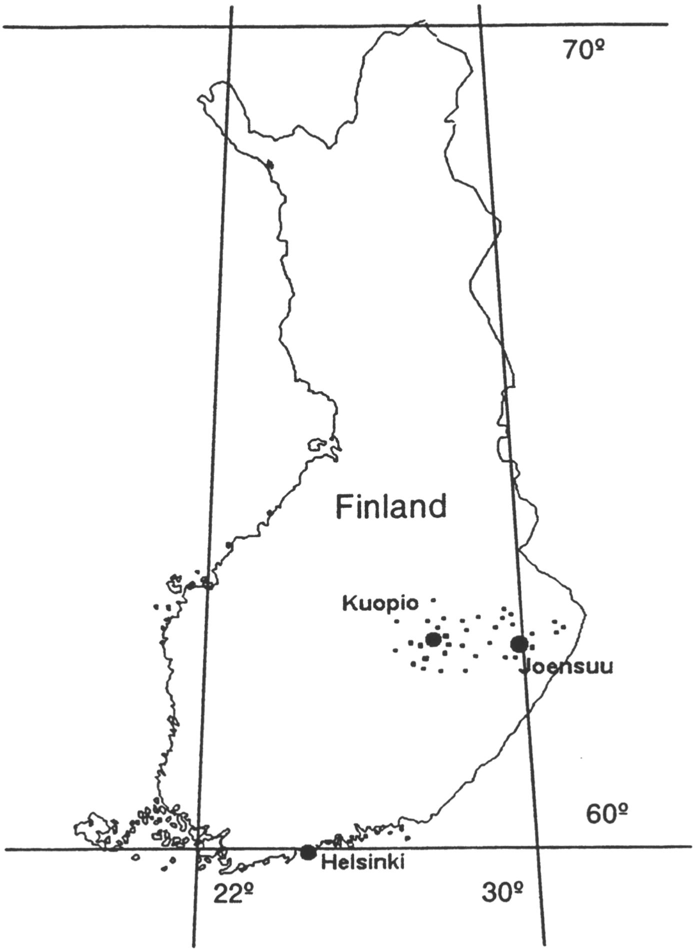

Figure 1. The material for this study includes 33 stands situated in the provinces of North Karelia and North Savo in eastern Finland.

length of rot were registered. The stems were also cut into short pieces in order to detect the rot anywhere else in a stem that could have started from a broken branch. The average characteristics for rot diameter at stump height (mm) and rot length (m) are presented in Table 3.

Weibull distribution

Because the trees were chosen by angle-count sampling, the diameter distribution was weighted by basal area and therefore called basal area diameter distribution (e.g. Maltamo et al. 1995). Basal area diameter distributions have been mainly used in Finland (e.g. Kilkki and Päivinen 1986; see also Gove

Table 1. Mean stand characteristics of the sample plot data.

Variable	Mean	sd	Min	Max
d_{gM}	13.3	2.890	7.8	19.6
h_{gM}	13.1	2.705	5.9	18.3
h_{dom}	13.9	2.271	8.0	18.0
T	31.8	6.521	16.0	50.0
G	17.8	6.112	6.0	36.0

Explanation of the variable codes: sd = standard deviation, Min = minimum value of variable, Max = maximum value of variable, d_{gM} = median tree diameter at breast height, cm; h_{gM} = median of tree heights, m; T = mean stand age, yr; h_{dom} = average dominant height, m; G = basal area, m^2 ha^{-1}.

Table 2. Mean characteristics of the sample tree data.

Variable	Mean	sd	Min	Max
$d_{1.3}$	12.8	4.366	3.8	25.8
h	12.7	3.010	2.6	20.4
h_{flb}	6.9	2.396	1.2	14.1
h_{fdb}	4.3	2.568	0.5	11.2

Explanation of the variable codes: sd = standard deviation of variable, Min = minimum value of variable, Max = maximum value of variable, $d_{1.3}$ = diameter at breast height, cm; h = total tree height, m; h_{flb} = height to the first living branch, m; h_{fdb} = height to the first dead branch, m.

and Patil 1998). In the study of Kilkki and Päivinen (1986), it was stated that a small number of measured trees from angle-count sample plot can be used to estimate parameters for the Weibull-distribution. However, a more reliable description of tree stock is obtained if there are several angle-count sample plots in one stand and they are combined to estimate the parameters of the Weibull-distribution (Maltamo et al. 1995; Maltamo 1997).

Sample plots were combined for each stand to get a more reliable basal area diameter distribution. Consequently, there were an average of 40 sample

Table 3. Summary of rot statistics.

Variable	Mean	sd	Min	Max
RDSH	51.82	32.08	10.00	150.00
LR	4.87	2.88	1.00	16.50

Explanation of the variable codes: *RDSH* = rot diameter at the stump height, mm, *LR* = length of the rot, m.

trees per stand. Theoretical basal area diameter distributions were fitted using the two-parameter approach of the Weibull distribution. The probability density function of the two-parameter Weibull distribution is:

$$f(x) = \begin{cases} \frac{c}{b}\left(\frac{x}{b}\right)^{c-1} \exp\left(-\left(\frac{x}{b}\right)^{c}\right), & (0 \leq x < \infty) \\ 0, & (x < 0) \end{cases} \tag{1}$$

where x is random variable (tree diameter), b is scale parameter, and c is shape parameter.

Weibull parameters for each sample plot were estimated using maximum likelihood estimation by solving the natural logarithm of the likelihood function of the Weibull density function. After the Weibull distributions were estimated, their parameters were regressed using mean stand characteristics as explanatory variables.

Height models

Due to the assumed correlation between sample plots and trees in one stand, mixed models were used when tree height and heights to the lowest living branch and the lowest dead branch were modelled. In these models, the generalized least square (GLS) method was used. The GLS method divides the residual variation of the model into variances between stands, between plots in a stand and among trees in a plot. The covariance structure of the material is taken into account in the parameter estimates (Lappi 1986). The fixed part of the model consists of explanatory variables and the random part includes stand, plot and tree effects in this case. When the reliability of these models was determined, stand and plot effects were calculated using sample tree measurements and estimated residual variances (Searle 1971). These calculated effects were then used to calibrate the height models.

Taper equation

Stem volumes were calculated using tree taper function instead of volume equations. As a result, it was more flexible to calculate volume estimates for different proportions of the tree stem. There are various ways to determine tree taper mathematically. In Finland, the most common taper estimation approach is the so called *polynomial taper curve* method. Although, the polynomial taper curve method has mainly been used and studied on most of the common Finnish tree species (Scotch pine, Norway spruce, birch), it has also been applied successfully on other tree species elsewhere (Määttä 1987; Heinonen et al. 1996). For example, in a study on *Eucalyptus cloeziana* (F. Muell.), Eerikäinen et al. (1999) found the *polynomial taper curve* method to be the most accurate stem diameter and volume estimator when compared to *Schumacher's taper equation* (e.g. Reed and Green 1984) and *diameter prediction* method (Van Laar 1985).

In the polynomial taper curve method, a diameter at 20% height was recommended by Laasasenaho (1982) to be used as the basic diameter in the construction of the mean tree taper. If the relative diameters $d_i/d_{0.2h}$ are from the relative heights h_i/h, and relative heights are denoted as x_i, then the relative stem taper can be expressed as a function $f(x_i)$. The basic relative taper curve, i.e. the mean curve, is calculated using the weighted means of relative diameters at given relative heights (Laasasenaho 1982, p. 28). Usually, the basic relative taper polynomial has been defined by using a high-degree polynomial like Fibonacci-series (Laasasenaho 1982):

$$\begin{aligned} f(x) &= c_1 x + c_2 x^2 + c_3 x^3 + c_4 x^5 + c_5 x^8 + c_6 x^{13} + c_7 x^{21} + \\ &\quad c_8 x^{24}, \end{aligned} \tag{2}$$

where x is the relative height h_i/h. The mean taper polynomial is estimated as a function of tree diameter and height.

There are notable advantages to the polynomial method of taper estimation. These are: a) it gives continuous taper for a tree, b) it is simple mathematically, c) it is easily adapted for use in simulation systems, and d) the method is more flexible than most other systems in that it requires only a few diameter and height measurements for the estimation of volumes and diameters without compromising accuracy (can accurately predict volumes and diameters with only one diameter measurement at any tree height).

In the reliability tests of the taper polynomial (Kärki et al. 1999b), the relative biases ($\mathrm{Bias}_{\%}$) and root mean square errors ($\mathrm{RMSE}_{\%}$) of volume estimates ($\hat{v}_i$) were determined using the following formulas:

$$\mathrm{Bias}_{\%} = 100 \cdot (1/n \sum_{i=1}^{n} (v_i - \hat{v}_i))/(1/n \sum_{i=1}^{n} \hat{v}_i) \tag{3}$$

$$\mathrm{RMSE}_{\%} = 100 \cdot \sqrt{1/(n-1) \sum_{i=1}^{n} (v_i - \hat{v}_i)^2}/((1/n) \sum_{i=1}^{n} \hat{v}_i) \tag{4}$$

Tree rot equations

In the case of rot, the occurrence and length of rot was examined for each sample tree. Logistic regression was used to model the occurrence of rot in stems. Logistic regression is used when the independent variable receives only values of 0 or 1. If the explicable variable is binary, the parameters can be estimated with the Maximum Likelihood (ML) method (Cox 1989). In the

ML method, the parameter vector is defined so that the sample likelihood is possibly big or we are maximizing the probability of the sample. If the parameters have an effective estimate, the ML solution will produce it. In this study, the unknown parameters of the models were estimated with the ML method using forward stepping regression analysis. The c_0 is the only explanatory variable at the first step. At the next step, a variable that has the biggest χ^2 value is added to the model. The increment of variables is continued until no more significant variables at 95% confidence level are found (Hosmer 1989). In this case, rotten stems receive a value of 1 and sound stems a value of 0. Linear regression was used for modelling of rot length.

Results

Diameter distribution

Parameter models of fitted basal area diameter distributions of the Weibull distributions are presented in Table 4. Median diameter was used as explanatory variable for both parameters. Constructed models are very simple including only one explanatory variable. The degree of determination is high for parameter b but quite low in the case of parameter c. This result is similar to some previous studies concerning Weibull distribution (e.g. Rennolls et al. 1985; Maltamo 1997). The predicted basal area diameter distributions were scaled to stand level and validated using χ^2 statistics. The validation indicated that in only 1 of the 33 cases the predicted and true distributions disagreed.

Tree height and branch height models

In the case of the tree height model, tree diameter was the strongest explanatory variable (Table 5). Also, information about dominant height were able to be utilized in this model. The model concerning height to the lowest living branch showed similar results (Table 6). Stand and tree diameter and especially different height characteristics were used in this model. In the case of the lowest dead branch, only height to the first living branch could be used as a predictor (Table 6). This means that the applicability of this model is restricted to situations were some additional measurements in addition to normal stand mean characteristics are made. In all height models, the largest variation was the residual variation among trees in a plot. This is natural because sample trees represent different, and also extreme, positions in diameter distribution. The residual variation between stands was large for models for tree height and the lowest dead branch but in the case of height

Table 4. Parameter prediction models of the Weibull function.

Model variable	$\ln(b)$		c	
	Coefficient	T-value	Coefficient	T-value
Intercept	0.2915	2.04	9.4529	9.68
$\ln(d_{gM})$	0.9242	16.88	–	–
$\ln(G^2/d_{gM})$	–	–	−1.3841	4.26
RMSE	0.06		1.97	
RMSE-%	6.9		34.9	
$R^2_{adj.}$	0.90		0.35	

Explanation of the variable codes: b, c = parameters of Weibull distribution; d_{gM} = median tree diameter at breast height, cm; G = basal area, m^2 ha^{-1}; T-value = Students T statistic; RMSE = Root mean square error of model; RMSE-% = Relative RMSE of model,%; $R^2_{adj.}$ = Adjusted degree of determination of model.

Table 5. Mixed model for the total tree height (h, m).

Model variable	$\ln(h - 1.3)$		
	Coefficient	T-value	Z-value
Intercept	2.4223	18.92	–
$1/d_{1.3}$	−5.5862	−19.51	–
h_{dom}	0.0343	4.02	–
δ_b^2	0.0126	–	3.05
δ_w^2	0.0013	–	0.65
δ_t^2	0.0211	–	8.57

Explanation of the variable codes: $d_{1.3}$ = diameter at breast height, cm; h_{dom} = dominant height, m; δ_b^2 = random between stand effect; δ_e^2 = random within stand effect; δ_t^2 = random tree effect; T-value = Students T statistic: parameter estimate divided by its standard error; Z-value = random parameter estimate divided by its approximate standard error.

to the first living branch it was minimal. It seems that dynamics of height to the lowest living branch and the lowest dead branch differ from each other.

Polynomial taper equation

A taper polynomial was calculated using over bark diameters measured at relative heights. In most cases, when the taper curve approach is polynomial, a polynomial function has been based on the Fibonacci series (e.g. Laasasenaho 1982). In this study, the combination of lower polynomial terms

Table 6. Mixed models for h_{flb}(height to the first living branch, dm) and h_{fdb} (height to the first dead branch, dm).

Model variable	Coefficient ($\sqrt{h_{flb}}$)	T-value ($\sqrt{h_{flb}}$)	Z-value ($\sqrt{h_{flb}}$)	Coefficient ($\sqrt{h_{fdb}}$)	T-value ($\sqrt{h_{fdb}}$)	Z-value ($\sqrt{h_{fdb}}$)
Intercept	4.7077	8.00	–	4.2178	10.55	–
h_{flb}	–	–	–	0.0296	6.05	–
$d_{1.3}$	−0.0065	−2.33	–	–	–	–
d_{gM}	−0.0119	−2.70	–	–	–	–
h	0.0330	7.05	–	–	–	–
h_{dom}	0.0122	2.15	–	–	–	–
δ_b^2	0.0141	–	0.15	1.0871	–	2.61
δ_w^2	0.1659	–	1.19	0.1357	–	0.67
δ_t^2	1.2628	–	8.62	2.0316	–	8.66

Explanation of the variable codes: $d_{1.3}$ = diameter at breast height, mm; d_{gM} = median tree diameter at breast height, mm; h = total tree height, dm; h_{dom} = dominant height, dm.

with one logarithmic term gave the best results (e.g. Eerikäinen et al. 1999). For grey alder, the basic polynomial taper curve function was:

$$\frac{d_i}{d_{0.2h}} = c_0 + c_1x + c_2x^2 + c_3x^3 + c_4x^4 + c_5x^5 + c_6(\ln(x))^2 \tag{5}$$

where:

d_i = measured diameter
$d_{0.2h}$ = diameter at relative height of 20%
x = the relative height h_i/h
$c_0 \ldots c_6$ = coefficients

Parameter estimates and statistics for the taper polynomial are presented in Table 7.

The estimate for the relative diameter at 20% height ($d_{0.2h}$) is $d_i/f(x_i)$ where d_i is a measured diameter, that is usually at breast height ($d_{1.3}$), implying that $f(x_{1.3}) = f(1.3/h)$. The estimated taper curve function for a tree is:

$$f = \hat{d}_{0.2h} \cdot f_b(x), \tag{6}$$

where $f_b(x)$ is the basic polynomial taper curve and x is the relative height h_i/h.

The basic taper polynomial (Equation 5) gives the same average stem form for all trees of different sizes. However, each tree has its own shape.

Table 7. OLS (Ordinary Least Squares) – parameter estimates and statistics for the taper curve function.

Variable	Coefficient	T-value
c_0	1.2061	–
c_1	−1.6401	−5.81
c_2	4.6007	3.20
c_3	−10.4526	−3.14
c_4	10.0182	2.89
c_5	−3.7297	−2.85
c_6	0.0028	2.54
RMSE	0.005	
RMSE-%	0.7	

Because there are certain regularities in the diameter differences at relative tree heights (Laasasenaho 1982), an adjusted basic model for a given tree can be constructed as a function of the diameter at breast height and the total height of the tree ($f(d,h)$).

Differences between observed diameters and the basic taper polynomial ($f_b(x)$) were calculated; and correction equations (cpl_i) were estimated for diameter differences at relative tree heights of 10, 40 and 70% (Table 8). After the correction equations are applied, a cubic interpolation polynomial (Press et al. 1992, p. 114) can be calculated to pass through the calibration points. One extra point is needed for the tree top at relative height 100%, where the correction is 0. The final adjustment of the taper polynomial ($f_c(x)$) is achieved by adding the corresponding coefficients of basic taper equation and interpolation polynomial ($f_r(x)$) together: $f_c(x) = f_b(x) + f_r(x)$.

The reliability of the taper polynomial as a volume predictor was previously tested in a study on grey alder (Kärki et al. 1999b). In summary, the reliability figures of the total stem volume estimates calculated using the taper polynomial ($RMSE_{\%} = 9.049$, $Bias_{\%} = 0.373$) were comparable to those obtained by the new volume function for grey alder ($RMSE_{\%} = 9.001$, $Bias_{\%} = -0.036$) (Kärki et al. 1999b).

Rot in grey alder stems

The proportion of trees with rot at stump height seemed to vary irregularly as a function of age (Figure 2). The proportion of rot was minimum in age classes 30–50 years. The thinning method for grey alder stands could be the

Table 8. Correction polynomials (CPL_i) for the polynomial taper curve. Parameters are estimated using OLS-estimator.

Model	$CPL_{0.10}$		$CPL_{0.40}$		$CPL_{0.70}$	
variable	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value
Intercept	–	–	1.5805	2.83	−0.3887	−2.34
$d_{1.3}$	−0.0046	−2.40	–	–	–	–
h	0.0158	3.25	0.0625	3.71	–	–
$1/h$	−3.2785	−2.55	−2.6468	−2.71	2.5325	3.21
$\ln(d_{1.3})$	−0.2297	−2.72	–	–	0.2657	3.84
$\ln(h)$	–	–	−0.8489	−3.12	–	–
$1/\ln(h)$	0.8512	2.13	–	–	–	–
$d_{1.3}/(h - 1.3)$	0.3902	3.13	–	–	−0.5224	−5.32
$(d_{1.3})^2(h - 1.3)^2$	–	–	-5.8×10^{-7}	−2.27	–	–
$(d_{1.3})^2/(h - 1.3)^2$	−0.0566	−3.00	–	–	0.0769	3.95
$\bar{x}_{c_i}$	0.0018		0.0022		0.0015	
sd_{c_i}	0.0214		0.0620		0.0927	
RMSE	0.0207		0.0578		0.0862	
$R^2_{adj.}$	0.0538		0.1286		0.1346	

Explanation of the variable codes: CPL_i = correction polynomial for taper polynomial at relative tree height (h_i; i = 0.10, 0.30 and 0.70); $d_{1.3}$ = diameter at breast height, cm; h = total tree height, m; $\bar{x}_{c_i}$ = arithmetic mean of the dependent variable; sd_{c_i} = standard deviation of the dependent variable.

reason for the situation; in grey alder forests in Finland selection felling of sound trees have been practised. The situation presented in this study seems to be quite reasonable when compared to practice. More unexpected is the result that rot was more common in young age classes than in older ones. This could be a consequence of the regeneration in grey alder stands, because grey alder forests usually regenerate by root sprouting. If the older trees are rotten, it is expected that some of the younger sprouts will also show rot. In older age classes (over 50 years), the proportion of rotten trees increases with the length of the normal rotation time.

The very smallest trees seemed to be healthy (diameter class 4 cm), but already in diameter class 6 cm the proportion of rotten trees is 50% (Figure 3). Initially, it appears that the proportion of rotten sprouts is small but later the amount of rot increases as a consequence of harvesting damage.

The distribution of stands according to the proportion of rotten sample trees in the stand is presented in Table 9. Almost half of the stands had rot in less than 20% of the sample trees. In addition, 10% of the stands had rot in almost all sample trees.

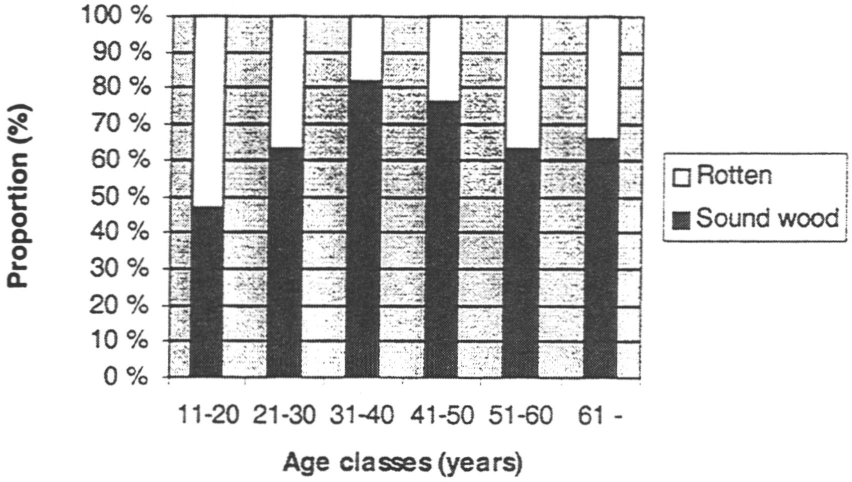

Figure 2. Proportion of rotten trees at stump height in different age classes.

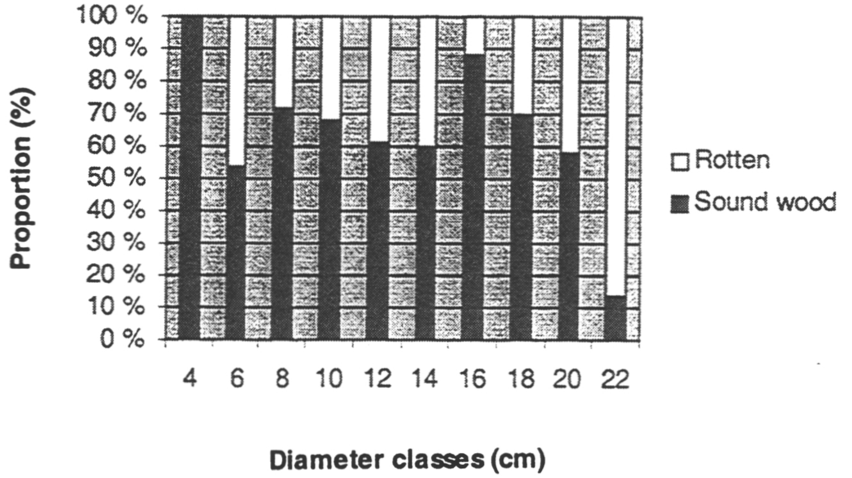

Figure 3. The proportion of rotten trees in stands at stump height sorted by diameter classes.

Using the data collected, logistic regression models were constructed for predicting the probability of rot in stems. Predictive variables were chosen by calculating correlations between variables describing rot and other tree characteristics. Two models were constructed for the whole material; the first ($i = 1$) was made for predicting the probability of rot at stump height and the second ($i = 2$) for predicting the probability of rot anywhere in a stem. The

Table 9. Frequency of rotten grey alder stems (at stump level).

Proportion of rot stems (%)	Number of stands	Stand frequency (%)	Cumulative frequency (%)
0–10	9	27.3	27.3
11–20	6	18.2	45.5
21–30	3	9.1	54.6
31–40	4	12.1	66.7
41–50	3	9.1	75.8
51–60	1	3.0	78.8
61–70	2	6.1	84.9
71–80	1	3.0	87.9
81–90	1	3.0	90.9
91–100	3	9.1	100
Total	33	100	100

logistic model for calculating the occurrence of rot in grey alder stems is as follows

$$PR_i = \frac{e^{y_i}}{1 + e^{y_i}} \qquad (7)$$

where:

PR = is the probability that there is rot in the stem
y_1 = $c_0 + c_1 B_{0.05h} + c_2 \ln(h_{fdb}) + c_3(1/T)$,
y_2 = $c_0 + c_1 B_{0.05h} + c_2 h_{fdb}$,
$B_{0.05h}$ = bark thickness at 5% height
h_{fdb} = height of the lowest dead branch and
T = stand age

The coefficients of Equations y_1 and y_2 are presented in Table 10.

It can be deduced from the form of the Equation 7, that the larger the value of the exponent the greater the probability of rot in an individual tree. Considering the effects of the variables in these models it can be said that the thicker the bark the greater is the probability that the tree has rot. As was also seen in Figure 2, the probability of rot decreases as age increases. The height of the lowest dead branch is also an indicator of rot. In the case of rot at stump height, the higher the lowest dead branches are the smaller is the probability of rot. In the other rot model indicating rot anywhere in the

Table 10. Logistic regression coefficients for predicting the occurrence of rot in alder stems.

Model	y_1			y_2	
variable	Coefficient	χ^2-value	Variable	Coefficient	χ^2-value
c_0	1.3767	–	c_0	−0.2964	–
c_1	0.2633	8.31	c_1	0.1809	5.12
c_2	−0.6713	8.14	c_2	0.0006	7.93
c_3	29.0155	5.01			
% correct	72.61			66.96	
χ^2-value	24.69			14.49	
G^2-value	290.43			307.89	

Explanation of the variable codes: χ^2 = value of χ^2-test; G^2-value = Log Likelihood – test value.

stem the situation is reversed. Thus, it seems that the relationship between the height to the lowest dead branch and occurrence of rot is complex. When considering the availability of the explanatory variables of these models it can be stated that the height of lowest dead branch is measured as a mean stand characteristics only in certain occasions such as planning for the saw timber production (Uusitalo 1995). Moreover, bark-thickness is not usually measured as mean stand characteristics, but it is typically measured in growth and yield sample plots.

To be able to predict the rot column in grey alder for situations when the volume of sound wood is of interest, two linear regression models were constructed (Table 11). The first was made for cases where the rot diameter at stump height is not known and the second for cases when a sample core is taken at stump height and the rot diameter is known.

The degree of the determination of the model without rot diameter at stump height was not very high. According to this model, the thicker the bark at 5% height the longer is the rot column, and the higher the first dead branch the shorter is the rot column. Basal area of the stand was also statistically significant in this model. If the rot diameter at stump height is known, the degree of the determination of the model is considerably increased. In this particular model, the effects of the height of the lowest dead branch and basal area are similar to those in the previous model.

Table 11. Regression coefficients for predicting the length of rot in alder stems.

Model variable	LR Coefficient	LR T-value	LR Coefficient	LR T-value
Intercept	4.5363	2.69	1.9296	2.50
$B_{0.05h}$	0.4295	3.83	–	–
$1/G$	15.0000	3.15	9.4892	2.41
H_{dbl}	–	–	−0.0027	−1.93
$Ln(h_{fdb})$	−0.8445	−3.02	–	–
RDSH	–	–	0.0563	6.33
RMSE	1.68		1.54	
$R^2_{adj.}$	0.13		0.40	

Explanation of the variable codes: *LR* = length of the rot, *RDSH* = rot diameter at the stump height, $B_{0.05h}$ = bark thickness at 5% height, *G* = basal area, h_{fdb} = height of the first dead branch, h_{dbl} = height of the dry branch limit.

The prediction of volume characteristics using varying sample tree information

The applicability of the height and taper-curve models to predict volumes of different parts of tree stems were tested using the same approach as in the study of Rouvinen et al. (1997). However, lowest dead branch and lowest living branch were in most trees located so near each other in tree stem that it was not sensible to calculate estimates for part of the stem which includes dead branches. Instead, the branchless part below lowest dead branch was considered. The other characteristics which were chosen was part of the stem below lowest living branch which includes both branchless and dead branches sections. In the study of Rouvinen et al. (1997), tree stem parts including branches of different quality were further divided into logs using cross-cutting. In this study, total volumes of these parts were directly calculated using varying information.

These calculations were done using the sample tree material of this study. Measured diameters at relative heights of the stem of sample trees were used in the cubic spline interpolation (Lahtinen and Laasasenaho 1979) to calculate estimates of the real stem volumes. When different height models were considered, tree diameters at breast heights were known. Tree and branch heights were predicted using the models in Tables 5 and 6, respectively. Different stem volumes were calculated using the constructed taper curve (Tables 7 and 8). To obtain more accurate volume predictions

Table 12. Reliability of different volume estimates (1–3) using Methods 1–4.

	Volume	RMSE	RMSE-%	BIAS	BIAS-%
Method 1	1	12.2	11.9	2.0	2.0
	2	9.9	11.4	0.5	0.6
	3	16.8	26.7	−2.5	−3.9
Method 2	1	9.9	9.6	1.5	1.4
	2	8.4	9.6	<0.1	<0.1
	3	17.0	26.9	−2.7	−4.3
Method 3	2	8.3	9.5	<0.1	<0.1
Method 4	3	13.2	22.1	0.8	1.4

Explanation of the variable codes: Volume 1 = estimated total volume; Volume 2 = estimated volume: stem volumes integrated from the ground to the first living branch; Volume 3 = estimated volume: stem volumes integrated from the ground to the first death branch; RMSE = Root mean square error of volume estimates, m^3; RMSE-% = Relative RMSE, %; Bias = Bias of volume estimates, m^3; Bias-% = Relative bias, %.

of different parts of the stem, different calibrations of the presented models were tested. Calibration was done by utilizing stand and plot effects which were calculated using sample tree measurements and estimated residual variances of mixed models. In these calibrations, it was assumed that sample tree characteristics were measured from a median tree as mean stand characteristics. The methods used were:

Method 1:	No calibration.
Method 2:	Calibration of the total tree height model (Table 5).
Method 3:	Calibration of the models for total tree height (Table 5) and height to the first living branch (Table 6).
Method 4:	Calibration of the models for total tree height (Table 5), height to the first living branch and height to the first dead branch (Table 6).

The results of the calculations are presented in Table 12. The accuracy of prediction of the total stem volume and volume to the first living branch were predicted almost as equal but in the case of volume to the lowest dead branch it was considerably worse. Calibration slightly improved the accuracy of all predictions. However, when only the model for total tree height was calibrated, the RMSE for prediction of the volume to the lowest dead branch was slightly increased.

Discussion

In this study, different models of tree and stand characteristics were constructed for grey alder. These models include diameter distribution, tree height, height to the first living and dead branch, taper curve and some rot models. The models can be applied basically with or without diameters.

1) **When only mean stand characteristics are known.** Diameter distribution is first predicted, and the theoretical tree diameters obtained from this distribution are used to predict total tree height and branch heights. Finally, volume characteristics can be determined using predicted tree diameter and height. In this situation, the average rot of the grey alder stock can be assessed using the information in Figure 3. However, in this study it was not possible to validate this procedure because there was no test material available for which the real stand structure was known.
2) **When tree diameters and sample trees are measured**, it is also possible to calibrate different height models and obtain more accurate information about these characteristics (Table 12). Correspondingly, the rot models presented in this study can also be applied to obtain more detailed information about amount of rot on the tree level. However, this requires some additional treewise measurements to be made.

The construction of different models indicated that there was much variation in grey alder stands that cannot be explained. Diameter distribution, tree height, height to the lowest and tree taper were able to be predicted using mean stand characteristics but prediction of other characteristics required additional measurements. Models of tree rot presented in this study included variables which are not normally measured in field measurements of forest management planning. This means that the applicability of these models is mainly on situations where some specific inventories are carried out. For example, stand inventory concentrating on tree quality or sawing production planning in certain grey alder stands could utilise models presented here.

The description of diameter distribution using the two-parameter approach of Weibull distribution prediction proved to be accurate in terms of χ^2 statistics. An alternative would have been to use percentile based distributions (Borders et al. 1987). In the study of Knowe et al. (1997), stand structure and dynamics of young plantations of red alder were considered. To produce current and future distributions, they compared different methods, including diameter distribution prediction and stand table projection by percentiles.

Prediction of branch-height characteristics, especially height to the first dead branch, proved problematic, due to the poor correlation between these characteristics and other tree dimensions. Also the calibration of these models using sample tree measurements only slightly improved the applicability of these models. This has also been found for other tree species (Rouvinen et al. 1997; Uusitalo and Kivinen 1998). However, branch-height characteristics are important when tree quality is considered. Rouvinen et al. (1997) proposed that average branch-height characteristics should also be measured in field inventories when other stand characteristics are collected. These variables could then be generalized directly for all trees of the stand. This was also tested in this study but the results were not good. Using non-parametric kernel-smoothing, Uusitalo and Kivinen (1998) developed a system for describing bivariate tree diameter and height to the first dead branch. The benefits of this kind of approach occur especially in situations where the correlation structures between certain characteristics are complex (Silverman 1986). However, these non-parametric methods require measurement of several sample trees per stand and could not be used for the material in this study.

When the reliability of the polynomial taper curve for grey alder (Equation 5) was tested in a previous study by Kärki et al. (1999b), the estimated relative bias and the standard error of stem volume estimates were about 0.4% and 9.0%, respectively (Kärki et al. 1999b). Laasasenaho (1982) found that when the taper polynomial (based on Fibonacci series) was used, the estimated relative standard error of the volume estimates varied from 7.2 to 8.5% for pine, spruce and birch. A good starting point for analysis of reliability is to compare volume estimates calculated with a taper polynomial to those estimated using a volume function. A simple nonlinear volume function for grey alder has been presented earlier (Kärki et al. 1999b) using the same data as used in this study for the taper polynomial. These two methods gave almost the same estimates of total stem volume. The taper polynomial was a more reliable and stable estimator, especially in the largest diameter classes.

Rot is more common in grey alder than in spruce which are common associates in eastern Finland. Mäkelä (1990) studied the probability of rot in Norway spruce stems. If we compare the results of these studies, some interesting differences can be seen. The proportion of rotten trees according to age classes was different from grey alder in these studies; in Norway spruce stands, the proportion of rotten trees was smallest in the beginning of the rotation time, while in alder, stands the proportion was smallest in the middle of the rotation time. The difference in alder stands could be explained as being due to the way alder regenerates (sprouting). There is another obvious difference in the diameter classes; the proportion of rotten Norway spruces is smallest in large diameter classes while in alder stands the proportion of rotten trees is highest in large diameter classes.

Norokorpi (1979) found that when $d_{1.3}$ and the age of the tree increase, the length of the rot in spruce stems shows a linear increase. In that study, the volume of the trees and the volume of the rot were also compared and found to be exponential. Tamminen (1985) has studied butt-rot in standing spruces. The variables described the form and growth of the stem of the sample trees (diameter increment at 1.3 m height in last 10 years). The success rate in the prediction model was 68%, which is comparable to the results of the present study. Mäkelä (1990) also obtained similar results for spruce; the success rate for prediction of rot in a tree was 60%. According to these studies, the success rates (73 and 67%) found in this study can be considered good. When comparing the proportion of rotten trees at stump height in different age classes in grey alder and white birch (Betula pubescens) (Verkasalo 1997), the proportion of rotten grey alder stems in different age classes is significantly lower than in white birch. A recent study of white birch (Verkasalo 1997) found that for trees of seed origin the proportion of trees with rot was 32, 37 and 45 percent for trees under 40 years, 41 to 60 years and over 60 years of age, respectively. The proportions were higher for trees of sprout origin for the same age classes, 45, 53 and 61 percent. The grey alder in the current study had 36, 29 and 33 percent trees with rot in the same age classes. This is a significant result while it is normally thought that the rot in grey alder is much more common than in other hardwood species in Finland.

Conclusions

The material used was not optimal for this type of study. Trees were chosen using a relascope, and the number of sample trees per plot was low. All measurements were made on temporary sample plots. The low number of sample trees affected the possibility to test different models together. However, in the earlier data on grey alder, which were based mainly on the national forest inventory, the number of sampled trees in pure stands of grey alder was very low. Earlier information about grey alder has come mainly from single measurements of grey alder trees in mixed stands. Consequently, this study and the constructed models reveal new and important information about pure stands of grey alder in eastern Finland.

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IV

Predicting the Value of Grey Alder (*Alnus incana*) Logs Based on External Quality

Timo Kärki

Kärki, T. 1999. Predicting the value of grey alder (*Alnus incana*) logs based on external quality. Silva Fennica 33(1): 13–23.

The quality of grey alder logs (*Alnus incana*) was studied by sawing sample logs from two different forests in November 1995–February 1996. For grading of grey alder logs and sawn timber the proposed system of Keinänen and Tahvanainen (1995) plus the reject -grade was used.

In general, grey alder logs have knots from the base to the top. All types of knots appear, and the length of the knot-free section is small at the base. In small-dimensioned logs there are fewer knots than in larger logs. Especially in large top logs, there were many more fresh knots than in other types of logs. Evidently, in different types of logs the different grades of sawn timber are located in comparable sections along the length. It also seems that the worse the grade class was, the longer was also the length of the class. The most common reasons for decreasing grade were dry knots and discoloration.

Keywords Alder, log quality, sawn timber quality, log value
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1 Introduction

Grey alder has had restricted use in Finland and is approved only for minor uses such as firewood. According to The 8th National Forest Inventory, in southern Finland the proportion of grey alder from the stem number varies from 0.9 % (Ahvenanmaa) to 18.2 % (Itä-Häme). The volume varies from 0.3 % (Lounais-Suomi) to 2.7 % (Pohjois-Savo). Of the alders growing in Finland, grey alder is more common than red alder (*Alnus glutinosa*) (Table 1). A significant proportion of red alder forests are planted compared to grey alder forests, which are all natural. The technical properties and use of grey alder wood have been studied by Schalin 1966, Alestalo and Hentola 1967, Hakkila 1970, Lehtonen etc. 1978, Björklund and Ferm 1982 and Kärki 1997a. The yield of grey alder have been studied by Miettinen 1933, Mäkinen 1984 and Valkonen etc. 1995.

In Finland, alder timber is used very little. According to Louna and Valkonen (1995), in

1993 about 20 000 m^3 of domestic alder timber was used. This is a rough estimate, which takes into account mainly the use of alder by large companies.

The system suggested by Keinänen and Tahvanainen (1995) for grading grey alder logs and sawn timber (Tables 2 and 3) was used in this study for valuing logs and timber. Here this classification is also used to test the suitability.

Several methods are used to study the internal quality of logs. The methodology and classification based on external defects have been studied by Orver 1970, Hanks 1976, Weslien 1983, Flink-

Table 1. Amount of alder timber in southern Finland (with bark) according to The 8th National Forest Inventory (1000 cbm).

Species	Logs	Industrial tree	Slash	Total
Grey alder	52	1660	749	2461
Red alder	237	1071	71	1380
Total	289	2731	820	3841

Table 2. Quality classification of grey alder logs (Keinänen and Tahvanainen (1995).

Factor of dimension or quality	Grade A	B	C
Top diameter	Min. 19 cm	Min. 15 cm	Min. 13 cm
Min. length	21 dm	21 dm	21 dm
	other lengths in intervals of 1 dm		
Accuracy of length	± 3 cm	± 3 cm	± 3 cm
Ring width	Even	No special requests	No meaning
Crook	2 cm/m	2 cm/m	3 cm/m
Number of knots per m / max. knot size			
– all knots	0 pcs	Max. 4 pcs	Max. 6 pcs
– fresh knots	Not allowed	Max. 2 pcs/3 cm	Max. 3pcs/7cm
– dry knots	Not allowed	Max. 2 pcs/3 cm	Max. 3pcs/4cm
– rotten knots	Not allowed	Not allowed	Max. 2pcs/3cm
Twist	Not allowed	Slightly allowed	No meaning
Cracks	Not allowed	Not allowed	Not restricted
Discoloration	Not allowed	Slightly allowed	Max. 1/2 diam.
Rot, centered	Max. 1 cm	Max. 5 cm	Max. 1/2 diam.

Table 3. Grading system for grey alder sawn timber, proposed by Keinänen and Tahvanainen (1995).

Factor of dimension or quality	Grade A	B	C
Min. width	180 mm	150 mm	130 mm
Max. number of knots, on the worse side and worst meter	2 pcs	3 pcs	5 pcs
From the number of knots can be, pcs/mm			
– fresh knots	2 pcs/10 mm	2 pcs/40 mm	3 pcs/60 mm
– dry knots	Not allowed	2 pcs/30 mm	3 pcs/40 mm
– rotten knots	Not allowed	Not allowed	1 pcs/30 mm
– bark knots	Not allowed	1 pcs/30 mm	1 pcs/40 mm
Cracks, over 100 mm length	Not allowed	Max. length 300 mm	Not restricted
Growth	Even	Not restricted	Not restricted
Tension wood, % of the length	Not allowed	Max. 10 %	Max. 20 %
Discoloration, % of the length	Not allowed	Max. 10 %	Max. 15 %
Rot centered, width	Not allowed	Max. 20 mm	Max. 50 mm

man 1985, Blomqvist and Nylinder 1988, Klinkhachorn et al. 1988, Harless et al. 1991 and Grace 1993. Uusitalo 1994 studied the prediction of sawn wood quality in pine stands. Verkasalo (1995) has listed possible reasearch methods for studying logs:

1. Traditional test sawing and grading of individual pieces of sawn timber
2. Test sawing used by Technical Research Center of Finland (VTT)
3. Describing the internal quality by X-ray and NMR-techniques
4. Describing the internal quality after rotary-cutting
5. Theoretical sawing (simulation)

In traditional test sawing, the logs are bucked and sawn according to the commercial patterns. The defects are measured or classified on the surfaces of the pieces of sawn timber, and the pieces are valued according to dimension, grade and price per unit volume. This method is used in the present study. In the VTT method, the logs are sawn into thin slices and the geometry of the slices and the position, quality and size of the knots are measured on a coordination table. According to this information, the stem or the log can be described mathematically with knots in XYZ-coordinates and sawn theoretically in given ways. They can then be graded and valued according to the dimensions, grades and prices per unit volume.

In X-ray (also called Computer Tomography CT) and NMR-techniques the internal quality of the log can be described by measuring the changes in timber, which can mean internal knots and other defects. An advanced method for describing the internal quality of the log is rotary-cutting, after which defects in the logs can be observed and measured from veneer by manual or automatized scanning methods. Theoretical sawing based on dimensions and external quality of the logs is one more option; these have been studied, for example, by Hallock and Galiger 1971, Richards 1979, Nakata 1986, Liljeblad et al. 1988 and Meimban 1991.

The aim of this study was to investigate the potential to predict the value of grey alder logs by external properties. This is divided into the following subaims:

1. Predicting the value of logs according to external properties.
2. Reasons for variation in quality of logs and sawn timber.
3. Quality distribution of sawn timber in logs of different type/grade.
4. Testing the suitability of the quality classification of Keinänen and Tahvanainen (1995).

2 Material and Methods

The research material comprised 229 grey alder logs from two pure grey alder stands, both situated in Northern Savo, one in Maaninka and the other in Nilsiä (Table 4). The trees were randomly selected with the limitation that the logs had to be sawable (stem form). Total log volume was 18.1 m^3. The logs were sawn during November 1995–February 1996. For grading grey alder logs and sawn timber the proposed system of Keinänen and Tahvanainen (1995) plus the reject -grade was used.

Top diameter (with bark) of the individual logs ranged from 112 to 295 mm. Most of the logs were in the top diameter classes of 13 cm to 18 cm. In the first stand (Maaninka) the logs were smaller than in the second stand (Nilsiä).

Table 4. Test logs divided into 1 cm top diameter classes.

Top diameter class	Stand 1	 2	Total
11	4	1	5
12	8	4	12
13	20	4	24
14	28	7	35
15	17	13	30
16	18	12	30
17	21	10	21
18	17	8	25
19	6	7	13
20	6	8	14
21	2	1	3
22	–	4	4
23	1	2	3
24+	1	1	2
Total	149	82	229

Table 5. Minimum, maximum and average values of sawlog data.

Variable	Minimum	Maximum	Average
Length (cm)	182	435	304.8
Top diameter with bark (mm)	112	295	159.8
Volume with bark (dm^3)	28	221	78
Quality	1	4	2.87
Saw timber –%	13.9	79.4	36.5

The average values for sawlogs are presented in Table 5.

Volume of sawlogs were calculated according to the formula:

$$V = \Pi\ 1/3\ l\ (R^2 + Rr + r^2) \quad (1)$$

where
V = volume of sawlog
l = length of sawlog
R = radius at butt end
r = radius at top end

Prior to sawing, the dimensions, shape, branchiness and other visible defects were measured at given intervals 0–0.5 m, 0.5–1.5 m, 1.5–2.5 m, 2.5–3.5 m and 3.5+ m. These factors needed to be measured to be able to classify the logs into different quality classes (Table 2). After this, the logs were sawn unedged (i.e. by flat slicing). This "saw-dry-rip" -method is commonly used when hardwood logs are sawn, in which the logs are first sawn unedged and the sawn timber (with bark) is then dried. Edging of sawn wood is performed after drying. The test logs were sawn into one dimension, 19 mm. After sawing, the sawn wood was graded according to the requirements listed in Table 3. The values for the sawn pieces and logs were calculated in the following way:

1 The sawn pieces were graded according to quality classifications (Table 3). The minimum length of one grade in a piece of lumber was 40 cm. This was estimated to be the minimum length of a component.

Table 6. Prices of grey alder sawn timber.

Grade	Price, FIM per m^3
A	2500
B	2000
C	1500
Reject	1000

2 The volume for each quality in a sawn piece was calculated.

3 According to quality and volume, the value for each sawn piece was calculated. The values used for different quality classes are shown in Table 6. The value for other wood material (by-products incl. bark), that could be used as firewood or material for fibre- or chipboards, was 150 FIM.

4 The values of individual sawn pieces and by-products in the log were used to calculate the value for the whole log. These log values were used in models.

The data were analyzed with SPSS software. An equation was devised by regression analysis to depict the relationship between the log value and the external properties of the log. The relationship between the grade of a piece of sawn timber and the location of that piece in the log was investigated by tabulation. The distribution of the knots in the different parts of the logs was investigated by cross-tabulation. The logs were grouped into four log grades in order to give at least 50 observations for each grade, but this procedure was not always successful.

3 Results

3.1 Quality of Logs

There were fewer fresh knots in small-dimensioned butt and top logs than in larger logs. Especially in large top logs, there were considerably more fresh knots than in other types of logs. In all types of logs, fresh knots were concentrated to the section from 1.5 to 2.5 m (Fig. 1).

Dry knots were concentrated at the base (0–0.5 m) of the logs and at a distance of 1.5–2.5 m (Fig. 2). There were almost twice as many dry knots in the top logs as in the butt logs.

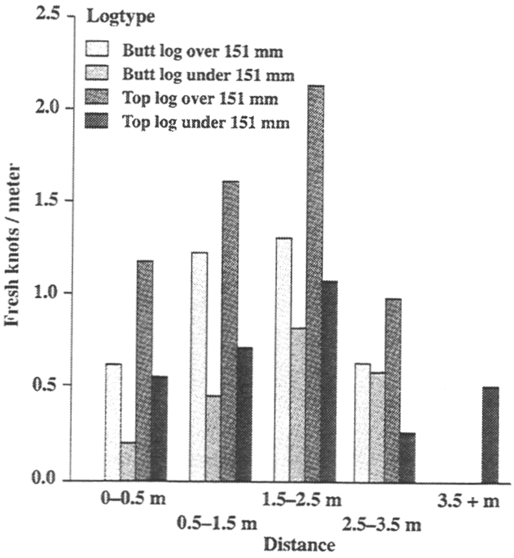

Fig. 1. Fresh knot distribution according to distance from the butt and the type and diameter of a log.

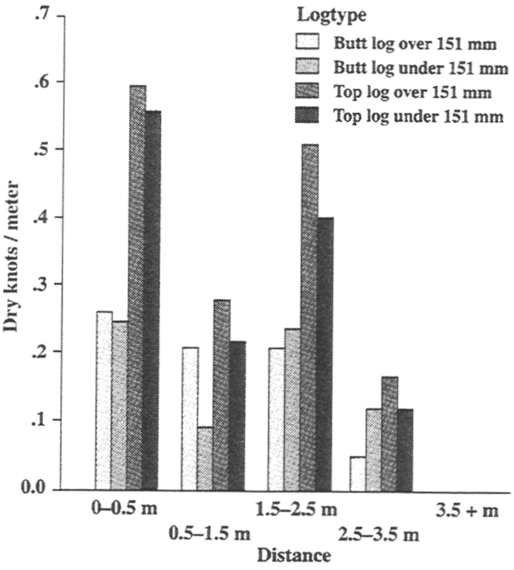

Fig. 2. Dry-knot distribution according to the distance from the butt and type and diameter of the log.

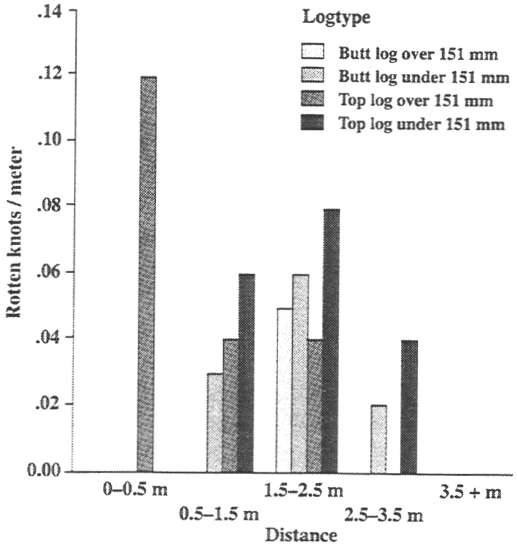

Fig. 3. Rotten-knot distribution according to the distance from the butt and type and diameter of the log.

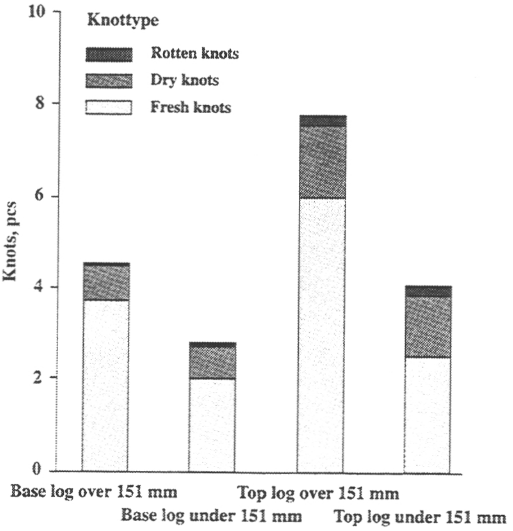

Fig. 4. Variation in the number of knot types in different types of 3.5-meter logs.

In large butt logs there were fewer rotten knots than in other types of logs. Rotten knots occurred most frequently in small-dimensioned top logs and were concentrated in the section from 0.5 to 2.5 m (Fig. 3).

Large top logs had more knots than other types of logs did. In large top logs, there were twice as many fresh knots as in small-dimensioned top logs. In general, top logs were more knotted than butt logs were, which was consistent with the process of self-pruning. Rotten knots were more common in top logs than in butt logs (Fig. 4).

Table 7. Distance distributions of graded sawn timber from the butt of the logs (all 229 logs).

Grade	Average distance from butt (cm)	Limit values (cm)
A	0–175	0–430
B	62–257	0–435
C	99–295	0–435
Reject	70–271	0–430

Table 8. Distance distributions of graded sawn timber from the butt (all 229 logs separated into four dimension classes).

Grade	Butt logs Top diameter > 151 mm	Butt logs Top diameter < 151 mm	Top logs Top diameter > 151 mm	Top logs Top diameter < 151 mm
	Average distance (cm)			
A	0– 91	4–140	0–102	2–127
B	65–252	74–267	46–250	58–253
C	113–299	107–302	95–276	81–304
Reject	78–280	62–251	97–301	58–282

Average values for different grades show that the grades are not equally distributed throughout the log (Table 7). Class A, i.e. knot-free sawn timber was mainly at the base of the logs. In this respect classes B, C and reject differed from each other only slightly. In Table 8, the logs are divided into four classes. The limit values show that each quality class occurred equally in logs.

Overall, it seems that in different types of logs the different grade classes were at the same distances. In the butt logs, class C began noticeably farther away from the butt than in top logs. It also seems that the worse the grade class was the greater was also the length of the class. So a rejected piece of sawn wood was usually rejected totally. The best grade class A was shorter than the other classes, and it could be combined with poorer quality classes (normally with classes B and C). The reasons for grade reductions are shown in Table 9.

Number of dry knots was the reason for reduction in sawn timber grade in half of the cases. This happens in every quality class. Another very remarkable reduction was seen in quality rejected; discoloration was the reason for quality change in almost half of the cases.

Table 9. Reasons for changing the quality in individual piece of sawn wood to a poorer qualityclass (percentage).

Reason for reduction in grade	Class B (A→B)	Class C (A,B→C)	Rejected (A,B,C→Rej.)	Total
Number of knots	12.2	17.3	5.6	13.3
Fresh knot	18.1	5.1	–	12.9
Dry knot	52.8	47.4	44.4	50.6
Bark knot	1.9	2.6	2.8	2.1
Rotten knot	7.2	9.0	–	7.2
Cracks	0.3	1.3	–	0.6
Discoloration	7.2	14.1	47.2	12.1
Rot	0.3	3.2	–	1.2
Total	100	100	100	100

Table 10. Results of the saw log grading.

Saw log quality	Number of logs	Volume with bark (m^3)	Proportion (%)
A	21	1.40	7.7
B	66	6.50	35.9
C	49	3.83	21.1
Rejected	93	6.40	35.3
Total	229	18.13	100.0

Table 11. Results of the sawn wood grading.

Sawn wood quality	Volume of sawnwood (m^3)	Proportion (%)
A	2.37	35.9
B	2.20	33.3
C	1.30	19.7
Rejected	0.74	11.1
Total	6.61	100.0

One aim of this study was to investigate how suitable the quality classifications of Keinänen and Tahvanainen (Tables 2 and 3) are. In Table 10 the results of the saw log grading are shown.

According to the classification (Table 2), only 65 % of the logs could be classified to A, B or C classes and 35 % of the logs belonged to the log grade Rejected (Table 10). The amount of log grade A was modest; only 7.7 % of the logs could be classified to grade A. 35 % of the saw logs were included in log grade B and 21 % to grade C.

Table 12. Correlation coefficients between the main predictors.

	FK1	FK2	FK3	FK4	DK1	DK2	DK3	DK4	TD
FK1	1.00								
FK2	.522	1.00							
FK3	.313	.487	1.00						
FK4	.012	.103	.316	1.00					
DK1	.035	–.690	–.191	–.090	1.00				
DK2	.021	–.004	–.053	–.102	.379	1.00			
DK3	.046	–.068	–.150	–.148	.447	.369	1.00		
DK4	.102	–.029	–.056	.013	.023	.117	.044	1.00	
TD	–.209	–.290	–.252	–.119	–.018	–.164	–.038	.054	1.00

FK1 = number of fresh knots from base to 0.5 m
FK2 = number of fresh knots from 0.5 m to 1.5 m
FK3 = number of fresh knots from 1.5 m to 2.5 m
FK4 = number of fresh knots from 2.5 m to 3.5 m
TD = top diameter of the log
DK1 = number of dry knots from base to 0.5 m
DK2 = number of dry knots from 0.5 m to 1.5 m
DK3 = number of dry knots from 1.5 m to 2.5 m
DK4 = number of dry knots from 2.5 m to 3.5 m

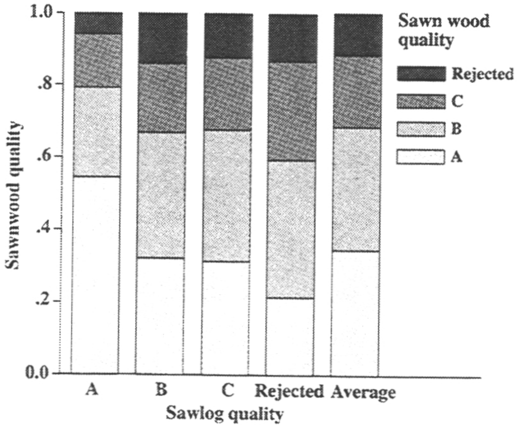

Fig. 5. Distribution of saw log grades and distribution of sawn wood qualities in various saw log grades.

When the results in Table 11 are compared to the log grades measured (Table 10), the main difference is the small amount of Rejected sawn wood. The volume of grade A sawn wood is significantly greater than could be predicted from the log grading. In Figure 5 we can see the relation between grades of the logs and quality of the sawn wood. From the figure can be seen what kind of sawn wood could be obtained from different grades of logs (A, B, C, Rejected). We can also see the average distribution of sawn wood qualities.

From the grade-A saw logs we reached over 50 % grade-A sawn wood. The proportion of rejected sawn wood was very small (6 %). The sawn wood quality in log grades B and C do not differ. In both log grades the distribution of sawn wood classes is similar. The log grade Rejected includes the least grade-A sawn wood, but the volume of grades B and Rejected sawn wood are equal to the better sawlog qualities (B and C). Average amount of grade-A sawn wood in the sawlogs was 36 %, for grade-B 33 %, for grade-C 20 % and for the Rejected class 11 %.

3.2 Models for Predicting the Value of Logs

The correlation matrix between the main predictors is shown in Table 12. These 9 factors were used when the final models were built. The other factors, such as twist and cracks, were not significant, so the correlation matrix for them is not presented.

The largest correlations were between FK2 and DK1 and between FK1 and FK2. These correlations were taken into consideration when the regression models were built. The correlations between the predictors used in the models are smaller than ±0.252 (between FK3 and TD). The regression models used for predicting the value for grey alder logs based on external quality are shown in Table 13.

The models were made in order to predict the value of different kinds of logs. There are sepa-

Table 13. Regression models for predicting the value of grey alder logs.

X-variable	B	SE B	Beta	t	p >
Model 1: Value of butt logs (FIM), $R^2 = 0.34$, SEE = 21.87, n = 136					
Intercept	–4.20				
TD	0.43	0.11	0.34	3.84	0.0002
Model 2: Value of top logs (FIM), $R^2 = 0.29$, SEE = 15.26, n = 93					
Intercept	53.24				
DK3	–3.66	1.91	–0.21	–1.92	0.0584
FK3	–2.19	0.91	–0.26	–2.42	0.0177
Model 3: Value of top logs incl. top diameter (FIM), $R^2 = 0.37$, SEE = 14.91, n = 93					
Intercept	4.21				
DK3	–3.53	1.86	–0.20	–1.90	0.0615
FK3	–2.16	0.89	–0.26	–2.44	0.0170
TD	0.36	0.16	0.23	2.23	0.0288
Model 4: Value of all logs (FIM), $R^2 = 0.31$, SEE = 22.29, n = 229					
Intercept	67.56				
DK2	–7.99	3.43	–0.16	–2.33	0.0210
FK3	–3.96	0.99	–0.27	–3.99	0.0001
Model 5: Value of all logs incl. top diameter (FIM), $R^2 = 0.57$, SEE = 19.16, n = 229					
Intercept	–7.86				
FK3	–1.91	0.88	–0.13	–2.17	0.0310
TD	0.45	0.05	0.53	8.76	0.0000

B = coefficient of regression, SE B = standard deviation of regression coefficient, Beta = standard coefficient of regression, t = value of t-test, p = level of risk.

rate models for butt and top logs. In explanation of the models there are differences in interpretations. In Model 1 there were no significant external signs of quality that could be used in prediction; obviously, for the knot-free base section of a log the only external signs that can be used are dimensional (e.g. top diameter and length).

In Model 2 all the coefficients are negative, which means that all knots (fresh and dry) decrease the value of the stem. This is a direct result of prefering the knot-free timber as the most valuable. Dry knots decrease the value more than fresh knots do. The knottiness at the section from 1.5 m to 2.5 meters is the most significant predictor from quality signs. The standard error is smaller in Model 2 than in Model 1.

In Model 3 the coefficient of determination was larger than in Model 2. Top diameter of a log was included in Model 3 and the coefficient of determination improved slightly (37 %). The explanations for the coefficients in this model were logical; the top diameter increases the value of a log, and the dry and fresh knots decrease the value. As shown in Model 2, dry knots decrease the value more than fresh knots do. The knotness from the 1.5 m to 2.5 meters was the most significant as in Model 2. Of these six models the standard error for Model 3 was the smallest.

Model 4 gives the log value only according to the number of knots. The coefficients of determination for different variables are logical in interpretation. Both coefficients are negative, which indicates that knot-free timber is the most valuable. Dry knots influence the log value more than fresh knots do. In Model 5 the top diameter was included, which greatly increased the significance of the model. Here the coefficient of determination was 57 %, and the standard error was also smaller than in Model 4. Residual plots for the two most useful Models (3 and 5) are shown in the figures below (Figure 6).

The residual plot for top logs (incl. top diameter) has the smallest standard error (14.91). Model 5 has a large standard error but the residual is still symmetrical.

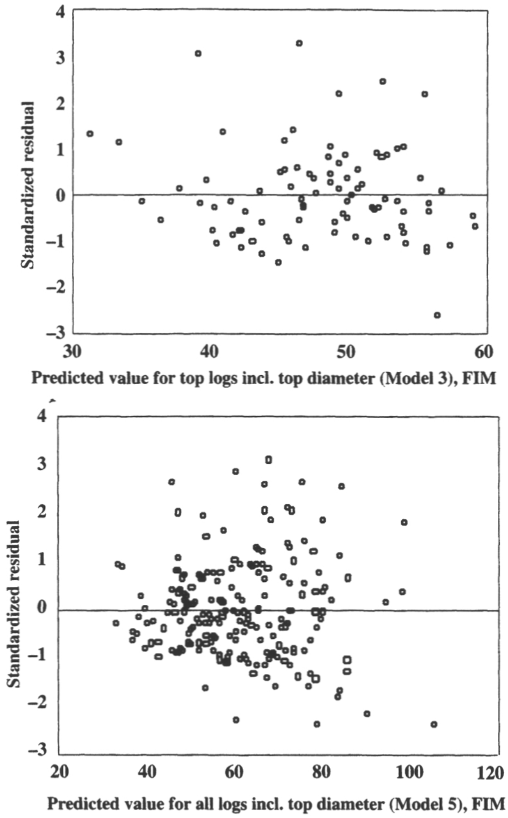

Fig. 6. Standardized residuals for Models 3 and 5.

4 Discussion

In general, grey alder logs have knots from the base to the top. All types of knots appear and the length of the knot-free section at the base is short. The difference between a dry-knot section and a fresh-knot section is not as obvious as, for example, with birch (Kärkkäinen 1986). In small-dimensioned logs there are fewer knots than in larger logs. Especially in large top logs, there are many more fresh knots than in other types of logs. It is interesting that dry knots are concentrated at the base of the logs (0–0.5 m) and in the section from 1.5 to 2.5 m. The number of dry knots in top logs is almost twice that in the butt logs. Rotten knots are concentrated in the section from 0,5 to 2,5 m.

Small-dimensioned butt and top logs are less knotty than large logs. If we compare these numbers of knots to the grade classification presented in Table 2, both averages could be included in grade-B. Large butt logs could be classified as grade-C and large top logs in the rejected category. Nevertheless, this is only a classification according to knottiness, in which the other quality factors (bends, cracks, discoloration etc.) are not taken into consideration. Overall, it seems that the different grades are located in comparable sections along the length in different types of logs. It also seems that the worse the grade class was, the longer was also the length of the class. The most common reasons for decreasing grade were dry knots and discoloration.

When the models for predicting the value of grey alder logs are considered, three models seemed to be valid: models predicting the value for butt logs (Model 1), top logs including top diameter (Model 3) and all logs including top diameter (Model 5). Models 2 and 4 (based only on external knot amount) were also logical, but the standard errors were slightly higher because the top diameter was not included.

The most important source of error in this material was the subjective sampling of experimental logs by two loggers. The trees were selected with the limitation that the logs had to be sawable (stem form). Those trees, from which the logs were cut, obviously were not the average trees in the stands as far as quality was concerned. On the other hand, according to the grades in Table 2, they were the best and largest trees. The measurements were made from only two stands. Along with the geographical concentration of the material, this permits only limited possibilities to apply the results elsewhere in Finland. Nevertheless, the material gives an indication of the quality of grey alder logs in the Savo-Carelian area.

Unfortunately, the size of the knots (beyond classification) was not taken directly into account when the logs and timber were classified; if they had been, it would have permitted more detailed analysis of the knot distribution in different kinds of logs. The knots were measured only partly in order to classify the logs and sawn pieces rightly. The grading used for grey alder logs and sawn timber (Tables 2 and 3) is also one source of error, because it is based on theoretical assumptions and the grade limits are fixed without empirical studies. This causes error when the grading is used for value predictions. Despite of these error possibilities, the reliability of the results can be considered good: one aim of the research was even to investigate the suitability of the classification (Tables 2 and 3) to practise.

It is possible to make grading rules for saw logs and sawn wood that are better than those used in these experiments (Keinänen and Tahvanainen 1995). In particular, there are problems in classifying the B and C logs; these types of logs do not differ enough. The problems could be avoided by allowing more dry knots in grades B and C; then the amount of rejected sawlogs would be comparable to that of rejected sawn wood. These classification rules, however, are a step in the right direction for better utilization of alder in Finland.

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Metsätieteen
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Harmaalepän (*Alnus incana*) tilavuustaulukot

Kärki, T., Eerikäinen, K., Heinonen, J. & Korhonen, K.T. 1999. Harmaalepän (*Alnus incana*) tilavuustaulukot. Metsätieteen aikakauskirja 1/1999: 39–49.

Tutkimuksessa esitetään harmaalepän tilavuusmalli yhtälön ja taulukoiden muodossa. Lisäksi tutkimuksessa esitetään kuoren osuuden malli ja dimensiovaatimusten mukaan lasketut tukkitilavuuden taulukot. Tukkitilavuudet vaihtelevat huomattavasti dimensiovaatimusten mukaan. Eri dimensiokriteerejä vertailtaessa on kuitenkin huomattava, että pienten latvaläpimittaluokkien käyttö sahauksessa edellyttää suoraa runkomuotoa, jotta pienten dimensioiden kannattava sahaus olisi mahdollista.

Harmaalepälle lasketut tilavuudet ovat pienempiä kuin vastaavan läpimittaisten koivujen tilavuudet, kun tarkastellaan läpimitaltaan suuria ($d > 15$ cm) mutta pituudeltaan lyhyitä ($h < 10$ m) puuluokkia. Tällöin harmaalepän taulukoidut runkotilavuudet suurimmissa läpimittaluokissa ovat enimmillään noin 10 prosenttia pienemmät kuin vastaavien läpimittaluokkien koivun runkotilavuudet. Kun tarkastelu kohdennetaan pituudeltaan suuriin mutta läpimitaltaan pieniin taulukoiden puuluokkiin, saadaan nyt esitetyllä harmaalepän tilavuustaulukolla suurempia runkotilavuuden ennusteita kuin koivun tilavuustaulukolla. Erot tilavuuksissa ovat tällöin enimmillään 11 prosenttia.

Asiasanat: harmaaleppä, tilavuustaulukot, kuorimallit

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1 Johdanto

Nopeakasvuinen kaskimaiden pioneeripuu leppä on ollut tutkimusten kohteena jo 1930-luvulta lähtien, jolloin Miettinen (1933) julkaisi luonnontilaisena kehittyneiden harmaalepikoiden kasvu- ja tuotostaulukot. Ensimmäisiä harmaaleppää käsitelleitä tutkimuksia oli myös Kalelan (1936) julkaisu, jossa selvitettiin kuusi-harmaaleppäsekametsiköiden kasvua. Harmaalepän soveltuvuutta paperin raaka-aineeksi on tutkittu useassa tutkimuksessa (mm. Routala ja Sihtola 1934, Bruun ja Slungaard 1957, Alestalo ja Hentola 1967). Harmaalepän on todettu olevan lyhytkuituisempaa kuin muut suomalaiset puulajit. Harmaalepällä sellun saanto ja repäisylujuus ovat huonompia kuin muilla puulajeillamme. Jännityslujuus ja opasiteetti, eli valoa läpäisemättömyys, ovat puolestaan harmaaleppäsellulla parempia kuin koivusellulla. Myös valkaisu on helpompaa harmaaleppäsellulla kuin koivusellulla, ja vaaleus on valkaisun jälkeen kestävämpää kuin koivusellulla. Sahateollisuuden raaka-aineena harmaalepän suosio on kasvanut voimakkaasti viime vuosien aikana mm. saunan lauteiden ja paneelien valmistuksessa (Kärki 1997a). Muita merkittäviä käyttökohteita lepälle ovat huonekalut, käyttö- ja koriste-esineiden valmistus sekä käyttö massa- ja kuitulevyteollisuudessa. Saksalaisessa huonekaluteollisuudessa leppää käytetään sopivissa kohteissa pähkinä- ja kirsikkapuun sekä mahongin korvikkeena (Grosser 1989). Taulukossa 1 on esitetty harmaalepän osuus kokonaispuustosta metsämaalla 15 eteläisimmän metsäkeskuksen alueella.

Harmaalepän osuus runkoluvusta on suurin Itä-Hämeen (18,2 %) ja Etelä-Savon metsäkeskusten alueella (16,3 %). Pohjapinta-alalla mitattuna Pohjois-Savon (4,2 %) ja Itä-Savon (3,9 %) metsäkeskusten alueilla harmaalepän osuus puustosta on suurimmillaan. Samanlainen on tilanne myös tilavuuden perusteella mitattuna. Tämä kertoo Itä-Suomen järeämmästä leppäpuustosta; osuus runkoluvusta on vähäisempi, mutta osuus tilavuudesta ja pohjapinta-alasta on tästä huolimatta suurempi kuin eteläisten ja läntisten metsäkeskusten alueella.

Harmaalepän teknisiä ominaisuuksia ja käyttöä lyhytkiertoviljelyssä on tutkittu Suomessa useassa eri yhteydessä. Harmaalepän tiheyttä ja kuiva-ainesisältöä ovat selvittäneet Hakkila (1970) ja Björklund ja Ferm (1982) sekä ominaisuuksia ja saatavuutta Grönros ym. (1995). Harmaalepikoiden biomassan tuotosta ja ravinteiden käyttöä ovat tutkineet Saarsalmi ym. (1983), Saarsalmi ym. (1985, 1991, 1992), Saarsalmi ja Mälkönen (1989) ja Saarsalmi (1995). Leppäpuun käyttöä ja markkinoita Suomessa ovat selvittäneet Louna ja Valkonen (1995) ja Kärki (1997a, 1997b).

Taulukko 1. Harmaalepän %-osuus runkoluvusta, pohjapinta-alasta ja tilavuudesta 15 eteläisimmän metsäkeskuksen alueella (VMI8).

	Runkoluvusta (%)	Pohjapinta-alasta (%)	Tilavuudesta (%)
Ahvenanmaa	0,9	0,6	0,4
Helsinki	2,7	1	0,7
Lounais-Suomi	1,3	0,4	0,3
Satakunta	2,6	0,9	0,6
Uusimaa-Häme	10,2	2,7	1,5
Pirkka-Häme	5,7	1,5	0,9
Itä-Häme	18,2	3,7	2,2
Etelä-Savo	16,3	3,2	1,8
Etelä-Karjala	7,7	2	1,2
Itä-Savo	14,9	3,9	2,4
Pohjois-Karjala	15	3,1	2
Pohjois-Savo	13,7	4,2	2,7
Keski-Suomi	10,1	2	1,2
Etelä-Pohjanmaa	1,2	0,6	0,4
Pohjanmaa	1,8	1,2	0,8
Keski-Pohjanmaa	4	1,6	1,3

Ensimmäiset laajat kotimaiset puiden tilavuustaulukot julkaisi Suomessa Ilvessalo (1947). Taulukoiden laadinta perustui graafiseen tasoitukseen. Laasasenahon (1982) julkaisemien männyn, kuusen ja koivun runkokäyrä- ja tilavuusyhtälöiden perusteella on julkaistu vastaavat tilavuustaulukot (Laasasenaho ja Snellman 1983). Kahteen muuttujaan, rinnankorkeusläpimittaan ja pituuteen, perustuvien tilavuusyhtälöiden avulla lasketut taulukot sisältävät tilavuudet yli 3 m:n mittaisille puille. Samassa tutkimuksessa on esitetty myös muutamiin suhteellisilta korkeuksilta mitattuihin läpimittoihin ja pituuteen perustuvat tilavuusyhtälöt.

Harmaalepän hyödyntämisen ja kaupan kannalta on olennaista, että puun kauppaa ja määrien arvioimista varten on olemassa pystypuun kuutiointiin soveltuvat tilavuustaulukot, kuten myös tukki/energiapuuosuuden arviointiin soveltuvat tilavuustaulukot. Harmaalepän runkomuotoa ja kuoritilavuuksia ovat tutkineet Mäkinen (1984) sekä Kärki ym. (1998). Viimeksi mainitussa tutkimuksessa selvitettiin runkomuodon lisäksi myös harmaaleppien runkomuotoa, laadun kehittymistä ja lahoisuutta. Harmaaleppätukeille on esitetty suomalaisessa kirjallisuudessa useampia eri laatuluokituksia. Keinänen ja Tahvanainen (1995) ovat esittäneet harmaaleppätukkien minimipituudeksi 21 dm:ä sekä minimilatvaläpimitaksi 13 cm:ä. Kärki (1997a) on esittänyt harmaaleppätukkien minimipituudeksi 20 dm:ä sekä minimilatvaläpimitaksi 8 cm:ä.

Tämän tutkimuksen tavoitteena on

a) laatia yksittäisen puun tilavuustaulukot
b) selvittää eri laatukriteereissä esitettyjen läpimitta- ja pituusvaatimusten vaikutus teoreettiseen tukkiosuuteen
c) laatia kuorimallit, joiden avulla voidaan estimoida kuoren osuus tilavuudesta millä tahansa rungon osalla.

2 Aineisto ja menetelmät

2.1 Aineisto

Tutkimuksen varsinaisena aineistona käytettiin touko–elokuussa 1996 harmaaleppämetsiköistä mitattua kertakoeala-aineistoa Savo-Karjalan alueelta (Pohjois-Savon ja Pohjois-Karjalan läänit). Mittaukset keskitettiin ko. alueelle, koska harmaalepän esiintyminen on runsaampaa ja harmaalepän taloudellinen merkitys on tällä alueella suurempaa kuin muualla Etelä-Suomessa (taulukko 1). Erillisiä luontaisesti syntyneitä metsiköitä mittauksissa oli 33 kappaletta, joista mitattiin 83 koealaa. Kultakin koealalta mitattiin kaatokoepuuna läpimitaltaan pienin ja suurin puu sekä pohjapinta-alamediaanipuu. Kaadetusta puusta mitattiin kaksi läpimittaa ristikkäin mm:n tarkkuudella 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80 ja 90 %:n suhteellisilta korkeuksilta. Kuorenpaksuus mitattiin kuorimittarilla 5, 20 ja 60 %:n suhteellisilta korkeuksilta kahdelta puolelta runkoa 0,5 mm:n tarkkuudella. Puun pituus mitattiin kaadon jälkeen mittanauhalla 10 cm:n tarkkuudella.

Kaatokoepuita kaadettiin yhteensä 230 kappaletta, joista 223 puuta käytettiin laskennassa (taulukko 2). Seitsemän kaatokoepuuta jouduttiin hylkäämään ilmeisten mittaus- ja kirjausvirheiden vuoksi. Lopullisen tutkimusaineiston analyysipuiden rinnankorkeusläpimitta ($d_{1.3}$) vaihteli 3,8 cm:stä 25,9 cm:iin keskiarvon ollessa 12,8 cm. Analyysipuiden kokonaispituuden (h) vaihteluväli oli 2,6–20,4 m ja keskiarvo 12,7 m.

Mitatut kaatokoepuut edustavat hyvin harmaalepälle ominaista kokojakaumaa, jossa sahauskelpoisten puiden rinnankorkeusläpimitta asettuu yleensä välille 15–20 cm ja pituus välille 10–14 metriä.

Edellä kuvattua aineistoa kutsutaan jäljempänä varsinaiseksi aineistoksi. Tutkimuksessa käytettiin testiaineistona myös Pohjois-Karjalan Ilomantsissa mitattuja 88 leppäkoepuuta. Aineistossa kustakin puusta on mitattu puun rinnankorkeusläpimitta, pituus sekä kuorelliset läpimitat samoilta suhteellisilta korkeuksilta kuin edellä kuvatussa aineistossa. Lisäksi aineistossa on mitattu kuoren paksuudet kaikilta luetelluilta suhteellisilta korkeuksilta. Aineisto edustaa maantieteellisesti suppeaa aluetta. Aineistossa havaittiin muutamia epäloogiselta vaikuttavia kuoren paksuuden arvoja. Tästä syystä aineistoa hyödynnettiin vain ennustettaessa varsinaiseen aineistoon puuttuvia kuoren paksuuksia. Jäljempänä aineistoa kutsutaan testiaineistoksi.

2.2 Tilavuustaulukoiden laadinta

Puusta mitattaviin pituus- ja läpimittatunnuksiin perustuvat tilavuusyhtälöt ovat usein tulomuotoisia (Laasasenaho 1982, Crow ja Schlaegel 1988). Ne ovat yksinkertaisia käyttää ja niiden avulla saadaan keskimäärin varsin tarkkoja tilavuusestimaatteja. Esimerkiksi Laasasenaho (1982) esittää männyn, kuusen ja koivun rinnankorkeusläpimittaan ja pituuteen perustuvien tilavuusyhtälöiden tilavuusestimaattien keskivirheiden vaihtelevan välillä 7,2–8,5 %.

Tilavuusyhtälö laadittiin 10 cm:n kannonkorkeudelta puun latvaan määritetyille kuorellisille runkotilavuuksille. Havaittuina eli mitattuina runkotilavuuksina käytettiin kuutiosplinimenetelmällä estimoituja tilavuuksia (Lahtinen ja Laasasenaho 1979). Interpolaatiosplinin toimivuus ja luotettava käyttäytyminen todettiin splinirunkokäyrien runkokohtai-

Taulukko 2. Koepuiden jakautuminen rinnankorkeusläpimitta- ja pituusluokkiin.

h, m	$d_{1.3}$, cm																							
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Σ
3		1																						1
4																								
5																								
6	1	3							1	1						1								7
7			2	1	1																			4
8			2	3	1																			6
9		2	4	3	2			1																12
10			1	3	6	1	6	3	1															21
11				3	1	2	1	6		1	3	2	1											20
12					5	1	6	6	3	3	1	3	2	1	1		1							33
13						2	4	4	2	2	2	1	2	1	3	1								24
14						1	6	1	2	2	2	3	4	6	1	1	1			1				31
15						1	3	2		1	1	4	3	1	1	2	2			2				23
16										1	3	3	7		2			1					1	18
17										2	1	1	2	2	4	1		1						14
18											1	1			1		1		1					5
19																	1							1
20														1			1	1						3
Σ	1	6	9	13	16	8	26	23	9	13	14	18	21	12	13	6	7	3	1	3			1	223

sessa graafisessa tarkastelussa. Analyysipuuaineiston spatiaalisesta hierarkiarakenteesta johtuen oli perusteltua olettaa, että eri havaintojen virhetermit ovat keskenään korreloituneita. Tästä alkuoletuksesta johtuen parametrit estimoitiin yleistetyn pienimmän neliösumman menetelmällä (ks. Lappi 1993, s. 64–68) käyttäen SAS-tilasto-ohjelman PROC MIXED –proseduuria (SAS 1992). Sekamallin kiinteän osan selittäjät valittiin testaamalla läpimitan (d) ja pituuden (h) erilaisia muunnoksia sekä niiden eri kombinaatioita. Harmaalepän runkotilavuudelle laadittu lineaarinen sekamalli oli muotoa:

$$\ln(v) = c_0 + c_1 d + c_2(d)^2 + c_3(\ln(d))^2 + c_4(\ln(h))^3 + b_i + w_{ij} + e_{ijk} \qquad (1)$$

missä

v = kuorellinen runkotilavuus, dm^3
d = rinnankorkeusläpimitta, cm
h = pituus, m
b_i = metsikön i satunnainen metsikkövaikutus
w_{ij} = metsikön i koealan j satunnainen koealavaikutus
e_{ijk} = satunnainen virhetermi metsikön i koealan j puussa k
$c_0..c_4$ = estimoitavia parametrejä.

Tilavuusyhtälön parametriestimaatit ja niiden luotettavuustunnukset esitetään taulukossa 3.

Mallin kokonaisjäännösvaihtelusta metsiköiden välisen vaihtelun varianssikomponentti $\hat{\sigma}^2_m$ selittää

Taulukko 3. Tilavuusyhtälön parametriestimaatit ja niiden luotettavuustunnukset.

Parametri	Estimaatti	Keskivirhe	p-arvo
c_0	0,6042	0,066	< 0,001
c_1	–0,4641	–0,089	< 0,001
c_2	0,0046	0,001	< 0,001
c_3	1,2356	0,136	< 0,001
c_4	0,0557	0,002	< 0,001
$\hat{\sigma}^2_m$	0,0005	0,002	0,36
$\hat{\sigma}^2_k$	0,0002	0,002	0,74
$\hat{\sigma}^2_e$	0,0078	0,002	< 0,001

Taulukko 4. Laadinta-aineistossa määritetyt läpimittaluokittaiset suhteellisen keskivirheen ($RMSE_i$) sekä absoluuttisen ja suhteellisen harhan (B_i) estimaatit tilavuus- (i = t) ja runkokäyräyhtälön (i = r) tilavuusestimaateille.

Läpimitta-lk	*n*	$RMSE_t$, %	$RMSE_r$, %	B_t, dm^3	B_r, dm^3	B_t, %	B_r, %
4	5	6,312	6,007	0,022	0,163	0,418	3,346
6	18	8,283	7,862	–0,221	–0,601	–1,789	–4,504
8	25	9,919	9,988	1,126	0,862	3,708	2,628
10	38	5,746	5,658	–1,038	–0,417	–1,887	–0,738
12	35	7,729	7,944	–0,546	0,512	–0,971	0,717
14	23	12,277	12,432	0,795	2,178	1,003	2,275
16	40	9,755	9,821	0,769	1,403	0,803	1,249
18	20	11,622	11,626	–2,953	–3,157	–2,258	–2,436
20	12	6,687	6,662	6,768	6,561	3,046	2,763
22–	7	4,257	2,796	–6,967	–1,767	–1,656	–0,288
Koko aineistossa	223	9,001	9,049	–0,053	0,552	–0,036	0,373

6 % ja metsiköiden sisäisen vaihtelun komponentti $\hat{\sigma}_k^2$ 2 % (taulukko 3). Metsiköiden välistä ja koealojen välistä vaihtelua kuvaavien satunnaistekijöiden estimaatit ovat lähellä nollaa. Mallin jäännösvaihtelun voidaan tulkita olevan pääasiassa puukohtaista satunnaisvirhettä. Käytettäessä sekamallin kiinteää osaa runkotilavuuden ennustajana on malliin ennen logaritmin palautusta lisättävä harhattomuuskorjaus (Baskerville 1972), joka yhtälön 1 tapauksessa on estimoitujen varianssikomponenttien summa jaettuna kahdella (0,0085/2 = 0,00425).

Tilavuustaulukoissa esitettävät harmaalepän kuorelliset runkotilavuudet estimoitiin harmaalepälle laaditulla tilavuusyhtälöllä. Rungon puutavaralajiositteiden osuudet kokonaistilavuudesta määritettiin runkokäyräyhtälöllä. Tilavuustaulukoiden laskennassa käytetty runkokäyräyhtälö esitetään Kärjen ym. (1998) tutkimuksessa. Tilavuustaulukoissa esitettävät puukohtaiset käyttöosan tilavuusestimaatit ovat siten runkokäyrällä määritetyn käyttöosan suhteellisen tilavuuden (v_{ko}/v_{kok}) ja tilavuusyhtälöllä ennustetun kokonaistilavuuden tuloja. Laskentamenetelmän valintaan oli vaikuttamassa se, että tilavuusyhtälö käyttäytyi loogisemmin kuin runkokäyräyhtälö aineiston pienimpien läpimittaluokkien äärialueilla ja aineiston ulkopuolella ekstrapolointitilanteissa.

Koska tilavuustaulukoiden laadinta suoritettiin käyttäen sekä tilavuus- että runkokäyräyhtälöä, katsottiin tärkeäksi suorittaa molempien menetelmien läpimittaluokittainen luotettavuustarkastelu, jossa luokitellulle aineistolle määritettiin eri tilastollisia virhetunnuksia. Taulukossa 4 esitetään sekä runkokäyrä- että tilavuusyhtälöllä laadinta-aineistolle estimoitujen runkotilavuuksien läpimittaluokittaiset keskivirheen ja harhan estimaatit.

Läpimittaluokittaisten keskivirhetunnusten perusteella voidaan todeta (taulukko 4), että menetelmät ovat lähestulkoon yhtä luotettavia. Kummallakin menetelmällä laskettujen estimaattien suhteellisen jäännösvirheen vaihtelu eri läpimittaluokissa oli samaa suuruusluokkaa ja koko aineistossa suhteellinen jäännösvirhe oli noin 9 %. Tilavuusestimaattien läpimittaluokittaisten harhan estimaattien etumerkki vaihteli eri läpimittaluokissa ja harhan estimaatit olivat itseisarvoltaan suurimpia suurissa läpimittaluokissa, mutta selitettävissä satunnaisvaihtelulla. Suhteellisen harhan estimaatit olivat lähes saman suuruisia sekä pienissä että suurissa läpimittaluokissa.

2.3 Kuorimallien laadinta

Varsinaisessa aineistossa kuoren paksuudet oli mitattu kolmelta suhteelliselta korkeudelta. Läpimitat olivat tiedossa 10 suhteelliselta korkeudelta. Kuorimallien laadinnan ensimmäisenä vaiheena oli kuoren paksuuden estimoiminen niille 7 suhteelliselle korkeudelle, joilta kuoren paksuuksia ei tunnettu. Testiaineiston epäluotettavuuden vuoksi kiinnitettiin kuoren paksuutta ennustavan mallin valinnassa erityistä huomiota mallin rakenteen loogisuuteen. Näin päädyttiin seuraavankaltaiseen osamalleista koostuvaan malliin.

1. Suhteellisen korkeuden 1 % kuoren paksuus ekstrapoloidaan mitatusta 5 % kuoren paksuudesta.
2. Suhteellisten korkeuksien 10 ja 15 % kuoren paksuudet interpoloidaan mitatuista 5 ja 20 %:n korkeuksien kuoren paksuuksista sekä korkeuksien 30, 40 ja 50 % kuoren paksuudet vastaavasti 20 ja 60 % korkeuksien kuoren paksuuksista.
3. Suhteellisten korkeuksien 70, 80 ja 90 % kuoren paksuudet interpoloidaan 60 %:n korkeudelta mitatun ja latvaan estimoidun kuoren paksuuksista.

Kohdan 1 ekstrapolointi tehtiin estimoimalla testiaineistosta regressiomalli:

$$b_{1\%} / b_{20\%} = a_1 b_{5\%} / b_{20\%} \tag{2}$$

missä b_x on suhteellisen korkeuden x kuoren paksuus (mm) ja a_1 on parametri.

Kohdan 2 interpoloinnit tehtiin estimoimalla malli

$$b_x = a_{1(x)} b_{5\%} + (1 - a_{1(x)}) b_{20\%}, \tag{3}$$

tai malli

$$b_x = a_{1(x)} b_{20\%} + (1 - a_{1(x)}) b_{60\%}, \tag{4}$$

missä $x = \{10\ \%, 15\ \%, 30\ \%, 40\ \%, 50\ \%\}$ ja $a_{1(x)}$ on suhteellisen korkeuden x kuoren paksuuden malliin liittyvä parametri.

Kohdan 3 interpoloinnit tehtiin estimoimalla malli

$$b_x = a_{1(x)} b_{60\%} + (1 - a_{1(x)})\, a_2 , \tag{5}$$

missä $x = \{70\ \%, 80\ \%, 90\ \%\}$ ja a_2 on parametri, joka voidaan tulkita kuoren paksuudeksi puun latvassa.

Parametri a_2 estimoitiin epälineaarisella regressiolla kullekin suhteelliselle korkeudelle (70, 80 ja 90 %) erikseen. Parametriestimaatit olivat lähes samat, kuten teorian mukaisesti tulee ollakin. Lopulliseksi parametriestimaatiksi valittiin korkeuden 90 % kuorimallin parametrien estimoinnin yhteydessä saatu estimaatti parametrille a_2. Muut edellä esitettyjen mallien parametrit estimoitiin pienimmän neliösumman menetelmällä. Saadut parametriestimaatit ovat taulukossa 5.

Taulukko 5. Kuoren paksuuksien ekstrapoloinnissa ja interpoloinnissa eri suhteellisille korkeuksille (x) käytettyjen mallien parametriestimaatit (a_1 ja a_2).

x, %	a_1	a_2
1	1,198	-
10	0,6255	-
15	0,3686	-
30	0,6702	-
40	0,5861	-
50	0,4016	-
70	0,7920	0,4865
80	0,4463	0,4865
90	0,2533	0,4865

Puun kuoretonta tilavuutta ennustavaa mallia valittaessa päädyttiin käyttämään selitettävänä muuttujana kuorettoman tilavuuden osuutta kuorellisesta tilavuudesta. Tämän muuttujan havaittiin riippuvan lineaarisesti puun läpimitasta. Pituus tai muut mahdolliset selittäjät eivät tulleet tarkasteluissa tilastollisesti merkittäviksi selittäjiksi. Täten mallin muodoksi tuli yhtälö 6:

$$v_u / v = a_0 + a_1 d \tag{6}$$

Jotta kuoreton tilavuus voitaisiin estimoida mille tahansa rungon osalle (esimerkiksi tukkiosalle), estimoitiin mallin 6 parametrit myös suhteellisille korkeuksille 5, 10, 15, 20, 30, 40, 50, 60, 70, 80 ja 90 %. Tällöin selitettävässä muuttujassa käytettiin kuorellista ja kuoretonta tilavuutta 1 % korkeudelta korkeuteen 5 %, 10 %, 15 % jne. Saatuja parametriestimaatteja selitettiin edelleen suhteellisella korkeudella. Sekä a_0- että a_1-parametriestimaattia selittävän mallin muodoksi valittiin kolmannen asteen polynomi:

$$a_0 = b_0 + b_1x + b_1x^2 + b_3x^3 \tag{7}$$

$$a_1 = b_4 + b_5x + b_6x^2 + b_7x^3 \tag{8}$$

Täten kuorettoman ja kuorellisen tilavuuden suhdetta kannon ja suhteellisen korkeuden x välisellä rungon osalla kuvattiin yhtälöllä 9:

$$v_u/v = b_0 + b_1x + b_1x^2 + b_3x^3 + (b_4 + b_5x + b_6x^2 + b_7x^3)d \qquad (9)$$

3 Tulokset

3.1 Tilavuustaulukot

Harmaalepän tilavuustaulukoissa 6, 7, 8 ja 9 esitetyt kuorelliset runkotilavuudet (dm^3) on määritetty yhden desimaalin tarkkuudella tilavuudeltaan alle 100 dm^3:n rungoille ja dm^3:n tarkkuudella yli 100 dm^3:n rungoille.

3.2 Kuorettoman osuuden mallit

Kuorettoman tilavuuden osuuden malliksi estimoitiin yhtälö:

$$v_u / v = 0{,}9415 - 0{,}00096 \times d \qquad (10)$$

Mallin 10 selitysasteeksi saatiin 0,015 ja läpimitan p-arvoksi 0,035. Mallin selitysaste on alhainen, sillä kuoren osuus tilavuudesta on lähes vakio puun koosta riippumatta (ks. taulukko 10).

Taulukkoon 10 on estimoitu yhtälöllä 10 kuorettoman tilavuuden osuus kuorellisesta tilavuudesta eri läpimittaluokissa.

Kuorettoman tilavuuden osuutta mille tahansa korkeudelle estimoivaksi malliksi saatiin yhtälö 11:

$$\begin{aligned} &v_u(x) / v(x) = \\ &0{,}0489x^3 - 0{,}1166x^2 + 0{,}0867x + 0{,}9226 \\ &+ (0{,}0001x^3 + 0{,}0003x^2 - 0{,}0005x - 0{,}0008)\, d \qquad (11) \end{aligned}$$

4 Tulosten tarkastelu

Harmaalepälle ei ole aiemmin esitetty puukohtaisia tilavuustaulukoita, siten tässä tutkimuksessa laaditun kokonaisrunkotilavuuden taulukon (taulukko 7) vertailukohdaksi valittiin Laasasenahon ja Snell-

Taulukko 6. Harmaalepän kuorellinen kokonaisrunkotilavuus (dm^3) 10 cm:n kannonkorkeudelta määritettynä.

h, m	$d_{1.3}$, cm																							
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2	1,4	2,2	3,4	5,1																				
3	1,4	2,3	3,6	5,4	7,6	10,4																		
4	1,6	2,5	3,9	5,8	8,2	11,2	14,6																	
5	1,7	2,7	4,2	6,3	8,9	12,2	15,9	20,2	24,9															
6	1,8	2,9	4,6	6,9	9,8	13,3	17,4	22,0	27,2	32,8	38,8													
7	2,0	3,2	5,0	7,5	10,7	14,5	19,0	24,1	29,7	35,9	42,4	49,3	56,6											
8		3,5	5,5	8,2	11,7	15,9	20,8	26,4	32,6	39,3	46,4	54,0	62,0	70,4	79,1									
9			6,0	9,0	12,8	17,4	22,8	28,9	35,6	43,0	50,8	59,1	67,8	77,0	86,5	96,5	107							
10				9,8	14,0	19,0	24,9	31,6	38,9	47,0	55,5	64,6	74,2	84,1	94,6	105	117	129	142					
11					15,3	20,8	27,2	34,5	42,5	51,3	60,6	70,5	81,0	91,9	103	115	128	141	155	169	185			
12						22,6	29,7	37,6	46,4	55,9	66,1	76,9	88,3	100	113	126	139	153	168	184	201	220	240	
13							32,3	40,9	50,5	60,9	72,0	83,8	96,1	109	123	137	152	167	183	201	219	239	261	284
14								44,5	54,9	66,2	78,3	91,1	105	119	133	149	165	182	200	218	239	260	284	309
15									59,6	71,9	85,0	98,9	114	129	145	161	179	197	217	237	259	283	308	336
16										77,9	92,2	107	123	140	157	175	194	214	235	257	281	306	334	364
17											99,8	116	133	151	170	190	210	232	254	278	304	332	362	394
18												126	144	164	184	205	227	250	275	301	329	359	391	426
19													156	177	199	221	245	270	297	325	355	387	422	460
20														190	214	239	265	292	320	351	383	418	455	496

Taulukko 7. Harmaalepän tukkiosan tilavuus (dm^3) 10 cm:n kannonkorkeudelta määritettynä, kun rungon osituskriteerinä käytetään tukin minimipituutta 21 dm ja latvaläpimittaa 13 cm (Keinänen ja Tahvanainen 1995).

h, m	$d_{1.3}$, cm											
	14	15	16	17	18	19	20	21	22	23	24	25
8		44,1	55,5									
9		46,7	59,4	71,8	84,1							
10		49,4	64,0	77,6	91,1	105	119					
11	34,5	51,6	67,9	83,5	98,8	114	129	145	162			
12	35,2	54,1	72,3	89,7	107	123	141	158	176	196	216	
13	36,1	56,9	77,3	96,5	115	134	152	172	192	213	235	259
14	37,4	60,4	83,1	104	125	145	165	186	208	231	256	282
15	39,1	64,8	89,9	113	136	158	180	202	226	251	278	306
16	41,5	70,4	98,1	124	148	172	196	220	246	273	301	332
17	44,7	77,6	108	135	161	187	213	239	267	296	327	360
18	49,4	86,8	119	149	177	204	232	260	290	321	355	391
19	56,2	98,2	133	164	193	223	252	283	315	349	385	423
20		107	146	180	211	243	274	307	342	378	416	458

Taulukko 8. Harmaalepän tukkiosan tilavuus (dm^3) 10 cm:n kannonkorkeudelta määritettynä, kun rungon osituskriteerinä käytetään tukin minimipituutta 30 dm ja latvaläpimittaa 13 cm.

h, m	$d_{1.3}$, cm											
	14	15	16	17	18	19	20	21	22	23	24	25
9			59,4	71,8	84,1							
10			64,0	77,6	91,1	105	119					
11			67,9	83,5	98,8	114	129	145	162			
12		54,1	72,3	89,7	107	123	141	158	176	196	216	
13		56,9	77,3	96,5	115	134	152	172	192	213	235	259
14		60,4	83,1	104	125	145	165	186	208	231	256	282
15		64,8	89,9	113	136	158	180	202	226	251	278	306
16		70,4	98,1	124	148	172	196	220	246	273	301	332
17		77,6	108	135	161	187	213	239	267	296	327	360
18	49,4	86,8	119	149	177	204	232	260	290	321	355	391
19	56,2	98,2	133	164	193	223	252	283	315	349	385	423
20		107	146	180	211	243	274	307	342	378	416	458

mannin (1983) esittämä koivun kuorellisen kokonaisrunkotilavuuden taulukko. Voidaan todeta, että harmaalepän tilavuusennusteet ovat pienempiä kuin vastaavat koivun tilavuudet, kun tarkastellaan läpimitaltaan suuria (d > 15 cm) mutta pituudeltaan lyhyitä (h < 10 m) puuluokkia. Tällöin harmaalepän taulukoidut runkotilavuudet suurimmissa läpimittaluokissa ovat enimmillään noin 10 prosenttia pienemmät suhteessa vastaavien läpimittaluokkien koivun runkotilavuuksiin. Kun tarkastelu kohdennetaan pituudeltaan suuriin, mutta läpimitaltaan pieniin taulukoiden puuluokkiin, saadaan nyt esitetyllä harmaalepän tilavuustaulukolla suurempia runkotilavuuden ennusteita kuin koivun tilavuustaulukolla. Erotukset ovat enimmillään 11 prosentin luokkaa. Tämä ero pienenee kuitenkin noin kuuteen pro-

Taulukko 9. Harmaalepän tukkiosan tilavuus (dm³) 10 cm:n kannonkorkeudelta määritettynä, kun rungon ositus- kriteerinä käytetään tukin minimipituutta 20 dm ja latvaläpimittaa 8 cm (Kärki 1997a).

h, m	$d_{1.3}$, cm																
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5		19,6															
6		20,7	27,0	33,5													
7	14,8	22,0	29,0	36,2	43,6	51,4											
8	15,3	23,3	31,2	39,2	47,4	55,9	64,7	73,8									
9	15,7	24,7	33,6	42,5	51,6	60,9	70,5	80,5	90,8	102							
10	16,1	26,2	36,1	46,0	56,0	66,3	76,9	87,8	99,1	111	123	136					
11	16,6	27,9	39,0	49,9	61,0	72,3	83,8	95,8	108	121	134	149	163	179			
12	17,2	29,8	42,1	54,2	66,4	78,8	91,4	104	118	132	147	162	178	195	214	234	
13	18,1	32,0	45,7	59,0	72,3	85,9	99,7	114	129	144	160	177	194	213	233	255	278
14	19,2	34,6	49,7	64,3	78,8	93,6	109	124	140	157	174	192	211	232	254	277	303
15		37,8	54,2	70,1	85,9	102	118	135	153	171	189	209	230	252	276	301	329
16			59,3	76,5	93,6	111	129	147	166	185	206	227	250	274	299	327	357
17				83,5	102	121	140	160	180	201	223	246	271	297	325	355	387
18					111	131	152	173	195	218	242	267	293	321	351	384	419
19						142	165	188	211	236	262	289	317	347	380	415	453
20							178	203	228	255	283	312	342	375	410	448	489

Taulukko 10. Kuorettoman tilavuuden osuus kuorellisesta tilavuudesta läpimitan funktiona.

d, cm	*vu*/*v*
1	0,941
2	0,940
3	0,939
4	0,938
5	0,937
6	0,936
7	0,935
8	0,934
9	0,933
10	0,932
11	0,931
12	0,930
13	0,929
14	0,928
15	0,927
16	0,926
17	0,925
18	0,924
19	0,923
20	0,922
21	0,921
22	0,920
23	0,919
24	0,918
25	0,917

senttiin, kun puuluokan pituus on 20 m ja rinnankorkeusläpimitta saa arvon 20 cm. Edellä tehtyjen tarkastelujen lähtökohtana ovat olleet tilavuustaulukon äärialueiden runkotilavuudet, joita voidaan pitää ekstrapolointeina. Harmaalepälle laaditun taulukon keskiosissa (d = 10, h = 10) tilavuudet ovat lähes yhtenevät koivun taulukon vastaavien läpimitta- ja pituusluokkien tilavuuksien kanssa. Läpimittaluokkaa 20 suurempien luokkien havaintojen vähyydestä johtuen (ks. taulukko 2) on tälle alueelle tilavuustaulukoissa esitettyihin runkotilavuuden ennusteisiin suhtauduttava varauksella.

Taulukoitujen puulajeittaisten runkotilavuuksien erojen syitä voivat olla puulajien toisistaan poikkeava runkomuoto sekä eritoten suurten puiden kohdalla eroa mahdollisesti aiheuttava erilainen kannonkorkeuden ts. puun kaatokohdan määritys, joka tässä tutkimuksessa oli kaikissa läpimittaluokissa 10 cm maanpinnan tasosta määritettynä. Vertailukohtana käytetyn koivun tilavuustaulukon (Laasasenaho ja Snellman 1983) tapauksessa tilavuuden integraalin aloittamiskohdaksi oli määrätty ylin kaatoa haittaava juurenhaaran niska, joka oli ennustettu erillisellä yhtälöllä. Kannonkorkeuden minimiksi oli asetettu kuitenkin 10 cm.

Tässä työssä on esitetty rungon kokonaistilavuuden sekä eri dimensiokriteereiden mukaiset teoreettisen tukkiosan tilavuusestimaatit harmaalepälle (taulukot 6–9). Tukin latvaläpimitan ja pituuden minimivaatimuksilla on huomattava vaikutus teoreettisen tukkiosan tilavuusestimaattiin. Estimoitaessa tilavuuksia Keinäsen ja Tahvanaisen (1995) asettamien minimidimensioiden mukaan tilavuudet muodostuvat huomattavasti pienemmiksi kuin Kärjen (1997a) asettamilla minimivaatimuksilla. Esimerkiksi 14 cm:n läpimittaisen lepän on oltava 11 m pitkä, jotta se tuottaisi tukkiosaa minimivaatimuksilla 13 cm / 21 dm ja peräti 18 m pitkä minimivaatimuksilla 13 cm / 30 dm. Minimivaatimuksilla 8 cm / 20 dm 14 cm:n paksuinen puu tuottaa tukkiosaa jo 7 m:n pituisena.

Eri dimensiokriteerejä vertailtaessa on kuitenkin huomattava, että pienten latvaläpimittaluokkien käyttö sahauksessa edellyttää suoraa runkomuotoa. Muutoin pienidimensioista puuta on järkevämpi käyttää esimerkiksi pyöreänä puuna rakentamisessa (Boren ym. 1998).

Taulukon 10 ja mallin 10 mukaan lepällä kuoren osuus tilavuudesta kasvaa puun läpimitan kasvaessa. Tulos on päinvastainen kuin esimerkiksi Mäkisen (1984) tutkimuksessa saatu tulos. Ero selittynee pääosin sillä, että Mäkisen aineistossa suurimmat harmaalepät olivat alle 15 cm läpimitaltaan, kun taas tämän tutkimuksen aineistossa on lähes 30 cm:kin läpimittaisia puita.

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34 viitettä

The photos in front cover:

Top left:
27-year-old grey alder forest in North Karelia,
G = 32 m^2/ha, H_{dom} = 16 m.
Photo: Timo Kärki

Middle left:
Western red alder *(Alnus rubra)* panels of B-quality.
Photo: Inland Wood Specialties, L.P.
United States

Down left:
Furniture made of red alder.
Photo: Pollmeier GmbH.
Germany

Top right:
Planing of grey alder wood. Mäntyharjun Viilu Oy.
Photo: Timo Kärki

Middle right:
3-layer plate made of grey alder. At left A-quality and at right B-quality.
Photo: Timo Kärki

Down right:
Furniture made of Finnish grey alder.
Photo: Oy Esse-Möbel Ab, Ähtävä.

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