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

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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	Stand 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:

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

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.

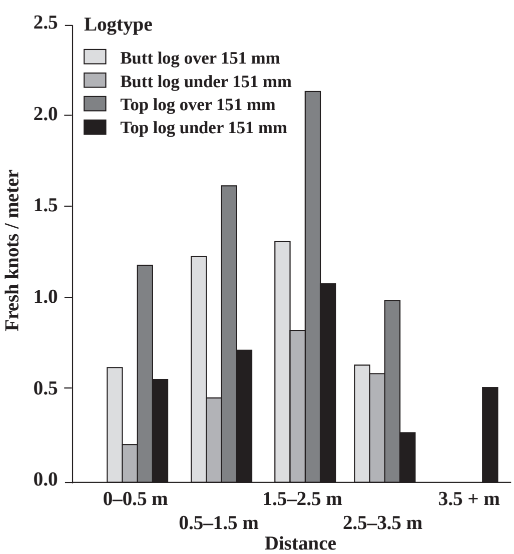

Fig. 1. Fresh knot distribution according to distance from the butt and the type and diameter of a log.

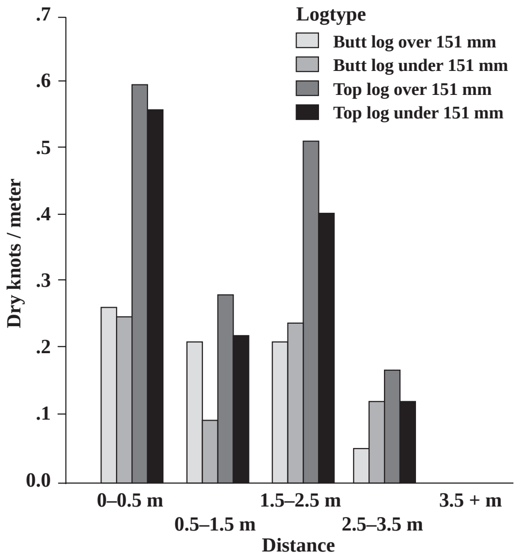

Fig. 2. Dry-knot distribution according to the distance from the butt and type and diameter of the log.

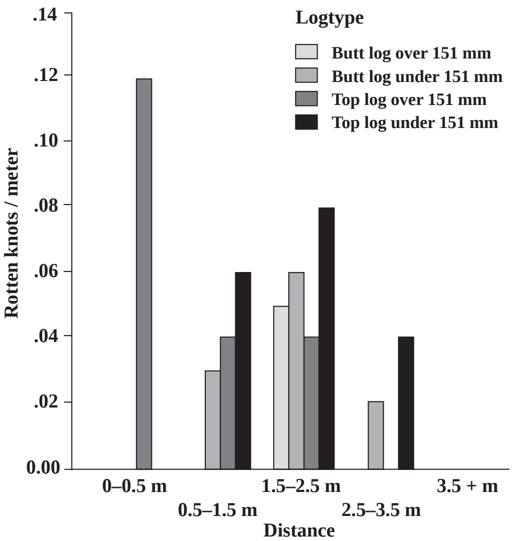

Fig. 3. Rotten-knot distribution according to the distance from the butt and type and diameter of the log.

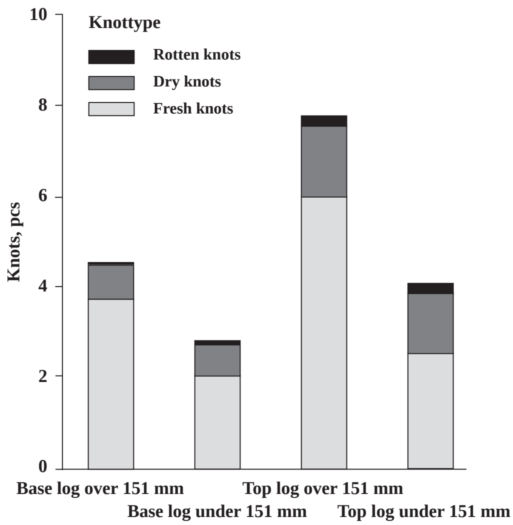

Fig. 4. Variation in the number of knot types in different types of 3.5-meter logs.

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

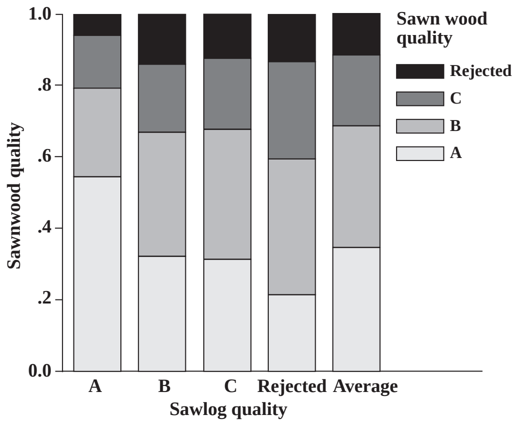

Fig. 5. Distribution of saw log grades and distribution of sawn wood qualities in various saw log grades.

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.

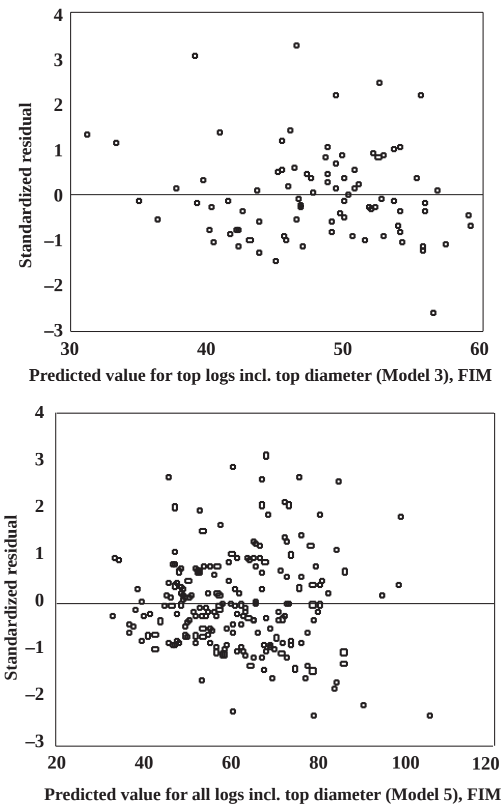

Fig. 6. Standardized residuals for Models 3 and 5.

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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References

Alestalo, A. & Hentola, Y. 1967. Alder in sulphate pulping. Paper and Timber 50(1): 25–27. (In Finnish with English summary).

Björklund, T. & Ferm, A. 1982. Pienikokoisen koivun ja harmaalepän biomassa ja tekniset ominaisuudet. Folia Forestalia 500. 37 p. (In Finnish)

Blomqvist, H. & Nylinder, M. 1988. Relation between geometry, yield and quality for sawlogs of spruce. Results from investigations at Rockhammar sawmill. Swedish University of Agricultural Sciences. Dep. of For. Products. Report 202. 51 p. (In Swedish with English summary).

Farmer, R.H. 1981. Handbook of hardwoods. Princes Risborough laboratory. London. 243 p.

Flinkman, M. 1985. A study of quality defects and their effect on the value of saw timber in grading according to VMR 1–81 and value grading system. Swedish university of Agricultural Sciences. Dep. of For. Products. Report 167. 66 p. (In Swedish with English summary).

Grace, L.A. 1993. Evaluating a prototype log sorting system for use in pine sawmills. Swedish University of Agricultural Sciences. Dep. of For. Products. Report 237. 43 p. (In Swedish with English summary).

Hakkila, P. 1970. Grey alder as pulpwood. Paper and Timber 12: 817–824.

Hallock, H. & Galiger L. 1971. Grading hardwood lumber by computer. Res. Pap. FPL 157. USDA Forest Serv., Forest Prod. Lab., Madison, WI.

Hanks, L.F. 1976. How to predict lumber-grade yields for graded trees. USDA Forest Serv. Gen. techn. rep. NE-20: 1–9.

Harless, T.E.G., Wagner, F.G., Steele, P.H., Taylor, F.W., Yamada, V. & McMillin, C.W. 1991. Methodology for locating defects within hardwood logs and determining their impact on lumber-value yield. Forest Prod. J. 41(4): 25–30.

Kärki, T. 1997. Sahauskelpoisen erikoispuun laatuvaatimukset ja käyttö Savo-Karjalan alueella. Folia Forestalia 1/1997: 37–48. (In Finnish).

Kärkkäinen, M. 1986. Malli männyn, kuusen ja koivun puuaineen oksaisuudesta. Abstract: Model of knottiness of wood material in pine, spruce and birch. Silva Fennica 20(2): 107–116. (In Finnish with English summary).

Keinänen, E. & Tahvanainen, V. 1995. Pohjolan jalot puut. Pohjois-Savon erikoispuiden käytön lisäämisprojekti. 160 p. (In Finnish).

Klinkhachorn, P., Franklin, J.P., McMillin C.W., Conners, R.W. & Huber H.A. 1988. Automated computer grading of hardwood lumber. Forest Prod. J. 38(3): 67–69.

Lehtonen, I., Pekkala, O. & Uusvaara, O. 1978. Technical properties of black alder (Alnus glutinosa (L.) Gaertn.) and great sallow (Salix caprea L.) wood and pulp. Folia Forestalia 344. 19 p. (In Finnish with English summary).

Liljeblad, Å., Johansson, L.G. & Drake, E. 1988. Quality simulation of sawlogs. Träteknik Centrum. Rapport I 8812081, Stockholm. (In Swedish with English summary).

Louna, T. & Valkonen, S. 1995. Kotimaisen raaka-aineen asema lehtipuiden teollisessa käytössä. Metsäntutkimuslaitoksen tiedonantoja 553. 38 p. (In Finnish)

Lövskog: björk, asp och al i skogsbruk och naturvård. 1989. Skogsstyrelsen. 255 p. (In Swedish)

Lutz, J.F. 1978. Wood veneer: Log selection, cutting and drying. U.S. Forest Service, technical bulletin 1577. 137 p.

Mäkinen, T. 1984. Harmaalepän ja tervalepän runkomuoto, kuorimallit ja runkokäyrämallit. Metsänarvioimistieteen pro gradu -tutkielma, Helsingin yliopisto. 60 p. (In Finnish)

Meimban, R.J. 1991. Simulation of hardwood sawmilling operations. Pennsylvania State University, Dep. of Forest Resources. Doctoral Thesis. 100 p.

Miettinen, L. 1933. Tutkimuksia harmaalepiköiden kasvusta. Metsätieteellisen tutkimuslaitoksen julkaisuja 18(1): 1–100 p. (In Finnish with German summary)

Nakata, K. 1986. Simulation of softwood-log sawing. J. Hokkaido For. Prod. Res. Inst. 3: 15–22 (In Japanese with English summary).

Orver, M. 1970. Grading of Scots pine saw timber using objectively measurable factors. Rapp. Inst. Virkeslära Skogshögsk. 66: 1–54.

Richards, D.B., Adkins, W.K., Hallock, H. & Bulgrin, E.H. 1979. Simulation of hardwood log sawing. USDA Forest Serv. Res. Pap. FPL 355. For. Prod. Lab., Madison, WI.

Schalin, I. 1966. Harmaalepän merkityksestä käytännön metsätaloudessa. Metsätaloudellinen aikakauslehti 83(9): 362–366. (In Finnish).

Söyrilä, P. 1992. Haapa viilun ja vanerin raaka-aineena. Paper and Timber 74(8): 622–627. (In Finnish).

Uusitalo, J. 1994. Sahatavaran laadun ennustaminen mäntytukkirungoista. Helsingin yliopiston metsävarojen käytön laitoksen julkaisuja 3. 53 p. (In Finnish)

Valkonen, S.. Rantala, S. & Sipilä A. 1995. Jalojen lehtipuiden ja tervalepän viljely ja kasvattaminen. Metsäntutkimuslaitoksen tiedonantoja 575. 112 p. (In Finnish).

Verkasalo, E. 1995. Järeän puun laadun tutkiminen. Seminaariesitelmä metsäteknologian tutkijoiden koulutuspäivillä 1995. Helsinki. 11 p. (In Finnish).

Weslien, H. 1983. Value grading of saw timber using objectively measurable factors. Part 1. Grading of pine timber. Sveriges lantbruksuniversitetet. Inst. För virkeslära. Rapport 140: 1–16.

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