ODC
526.5

FOLIA FORESTALIA 66

METSÄNTUTKIMUSLAITOS · INSTITUTUM FORESTALE FENNIAE · HELSINKI 1969

MATTI PALO

REGRESSION MODELS FOR ESTIMATING THE SOLID WOOD CONTENT OF ROUNDWOOD LOTS

N:ot 1—18 on lueteltu Folia Forestalia-sarjan julkaisuissa 1—41.
Nrs. 1—18 are listed in the publications 1—41 of the Folia Forestalia series.

1966 No 19 Paavo Tiihonen: Puutavaralajitaulukot. 1. Maan eteläpuoliskon mänty ja kuusi. 2,—

No 20 Seppo Grönlund ja Juhani Kurikka: Markkinapuun alueittaiset hankintamäärät vuosina 1962 ja 1964. Lopulliset tulokset.
Removals of commercial roundwood in Finland by districts in 1962 and 1964. Final results. 4,—

No 21 Kullervo Kuusela: Ålands skogar 1963—64. 2,—

No 22 Eero Paavilainen: Havaintoja kasvuturpeen käytöstä männyn istutuksessa.
Observations on the use of garden peat in Scots pine planting. 1,—

No 23 Veikko O. Mäkinen: Metsikön runkoluku keskiläpimitan funktiona pohjapinta-alan yksikköä kohti.
Number of stems in a stand as function of the mean breast height diameter per unity of basal area. 1,—

No 24 Pentti Koivisto: Itä- ja Pohjois-Hämeen koivuvarat.
Birch resources in the Forestry Board Districts of Itä-Häme and Pohjois-Häme. 1,—

No 25 Seppo Ervasti — Terho Huttunen: Suomen puunkäyttö vuonna 1964 ja vuoden 1965 ennakkotiedot.
Wood utilization in Finland in 1964 and preliminary data for the year 1965. 3,—

No 26 Sampsa Sivonen ja Matti Uusitalo: Puun kasvatuksen kulut hakkuuvuonna 1965/66.
Expenses of timber production in Finland in the cutting season 1965/66. 2,—

No 27 Kullervo Kuusela: Helsingin, Lounais-Suomen, Satakunnan, Uudenmaan-Hämeen, Pohjois-Hämeen ja Itä-Hämeen metsävarat vuosina 1964—65.
Forest resources in the Forestry Board Districts of Helsinki, Lounais-Suomi, Satakunta, Uusimaa-Häme, Pohjois-Häme and Itä-Häme in 1964—65. 3,—

1967 No 28 Eero Reinius: Valtakunnan metsien V inventoinnin tuloksia neljän Etelä-Suomen metsänhoitolautakunnan soista ja metsäojitusalueista.
Results of the fifth national forest inventory concerning the swamps and forest drainage areas of four Forestry Board Districts in southern Finland. 3,—

No 29 Seppo Ervasti, Esko Salo ja Pekka Tiililä: Kiinteistöjen raakapuun käytön tutkimus vuosina 1964—66.
Real estates raw wood utilization survey in Finland in 1964—66. 2,—

No 30 Sulo Väänänen: Yksityismetsien kantohinnat hakkuuvuonna 1965/66.
Stumpage prices in private forests during the cutting season 1965/66. 1,—

No 31 Eero Paavilainen: Lannoituksen vaikutus rämemännikön juurisuhteisiin.
The effect of fertilization on the root systems of swamp pine stands. 2,—

No 32 Metsätilastoa. I Metsävaranto.
Forest statistics of Finland. I Forest resources. 3,—

No 33 Seppo Ervasti ja Esko Salo: Kiinteistöillä lämmön kehittämiseen käytetyt polttoaineet v. 1965.
Fuels used by real estates for the generation of heat in 1965. 2,—

No 34 Veikko O. Mäkinen: Viljelykuusikoiden kasvu- ja rakennetunnuksia.
Growth and structure characteristisc of cultivated spruce stands. 2,—

No 35 Seppo Ervasti — Terho Huttunen: Suomen puunkäyttö vuonna 1965 ja ennakkotietoja vuodelta 1966.
Wood utilization in Finland in 1965 and preliminary data for the year 1966. 4,—

No 36 Eero Paavilainen — Kyösti Virrankoski: Tutkimuksia veden kapillaarisesta noususta turpeessa.
Studies on the capillary rise of water in peat. 1,50

No 37 Matti Heikinheimo — Heikki Veijalainen: Kiinteistöjen polttoainevarastot talvella 1965/66.
Fuel stocks of real estates in Finland in winter 1965/66. 2,—

1968 No 38 L. Runeberg: Förhållandet mellan driftsöverskott och beskattad inkomst vid skogsbeskattningen i Finland.
The relationship between surplus and taxable income in forest taxation in Finland. 2,—

No 39 Matti Uusitalo: Puun kasvatuksen kulut hakkuuvuonna 1966/67.
Costs of timber production in Finland during the cutting season 1966/67. 2, —

No 40 Jorma Sainio — Pentti Sorrola: Eri polttoaineet teollisuuden lämmön ja voiman sekä kiinteistöjen lämmön kehittämisessä vuonna 1965.
Different fuels in the generation of industrial heat and power and in the generation of heat by real estates in 1965. 2,—

No 41 Pentti Rikkonen: Havupaperipuiden kuorimishäviö VK-16 koneella kuorittaessa.
The barking loss of coniferous pulpwood barked with VK-16 machines. 2,—

No 42 Kullervo Kuusela ja Alli Salovaara: Etelä-Savon, Etelä-Karjalan, Itä-Savon, Pohjois-Karjalan, Pohjois-Savon ja Keski-Suomen metsävarat vuosina 1966—67.
Forest resources in the Forestry Board Districts of E-Sa, E-Ka, I-Sa, P-Ka, P-Sa and K-S in 1966—67. 3,—

No 43 Eero Paavilainen: Vanhojen rämemäntyjen kasvun elpyminen lannoituksen vaikutuksesta.
On the response to fertilization of old pine trees growing on pine swamps. 2,—

No 44 Lalli Laine: Kuplamörsky, (Rhizina undulata Fr.), uusi metsän tuhosieni maassamme.
Rhizina undulata Fr., a new forest disease in Finland. 1,—

Luettelo jatkuu 3. kansisivulla

FOLIA FORESTALIA 66

Metsäntutkimuslaitos. Institutum Forestale Fenniae. Helsinki 1969

Matti Palo

REGRESSION MODELS FOR ESTIMATING THE SOLID WOOD CONTENT OF ROUNDWOOD LOTS

ACKNOWLEDGEMENTS

This study was carried out at the Economics Department of the Forest Research Institute under the guidance of Professor Lauri Heikinheimo.

In the course of this work I have consulted Mr. HANNU VÄLIAHO on the application of the linear regression analysis. Mr. PENTTI NISULA and Mr. PENTTI RIKKONEN provided information on the availability of the source material. Miss PIRKKO WELLING assisted me in the tentative calculations. Mrs. HILKKA KONTIOPÄÄ translated the original Finnish text into English. This translation was checked by Mr. MICHAEL JONES. I wish to express my sincere thanks to all these persons.

Berkeley, California, November 1969

Matti Palo

CONTENTS

17507—69/80

REGRESSION MODELS FOR ESTIMATING THE SOLID WOOD CONTENT OF ROUNDWOOD LOTS

1. Introduction

A general presentation of the problem of the commensurability of the solid wood content of roundwood lots has been given earlier (PALO 1969, Section 4132). It was noted that conversion of the individual roundwood lots into the final, commensurate quantities expressed in cubic metres solid measure, as entered into roundwood removal and consumption statistics, carried a considerable risk of error. The size of this error varies according to roundwood assortment groups and removal districts. The practical conversion traditionally had two phases: (1) the conversion factor was looked up manually from a table for the specific roundwood assortment; (2) the roundwood content indicated by the relevant commercial measurement units was multiplied by the conversion factor on a table calculator. In the experimental statistics of 1962 on the removal of roundwood for sale (PALO 1964), phase (2) was fed into a computer. Even then, the conversion required considerable human work input. Because of the risk of error contained in the conversion factors, it was decided when planning the 1967 annual statistics on roundwood removal for sale to check the most important groups of conversion factors and, if possible, also feed phase (1) into a computer.

2. Coniferous saw logs

The conversion factors for coniferous saw logs used in the wood consumption studies and in the experiments with statistics on roundwood removal for sale were based on studies dating back to the 1920s (SAARI *et al.* 1929). They could be checked after the completion of a recent study of the top form factor for coniferous saw logs (ARO & RIKKONEN 1966). Pine and spruce logs in south Finland and spruce saw logs in north Finland were included in this study. Fig. 1 shows the model of the calculation system for the new conversion factors for these coniferous saw logs.

The initial state after measurement is shown on the left. A_1 indicates the volume in cubic feet. The diameter is measured in the following ways: A_2 at the top; A_3 by using a half-inch declining classification; A_6 in random direction; and A_7 with bark excluded. A_4 shows length in full feet, with an average allowance of 5.0 inches (ARO & RIKKONEN, 1966, p 7). The arrows indicate the conversion of the initial state, either directly or via an intermediate state, into the final state seen on the right.

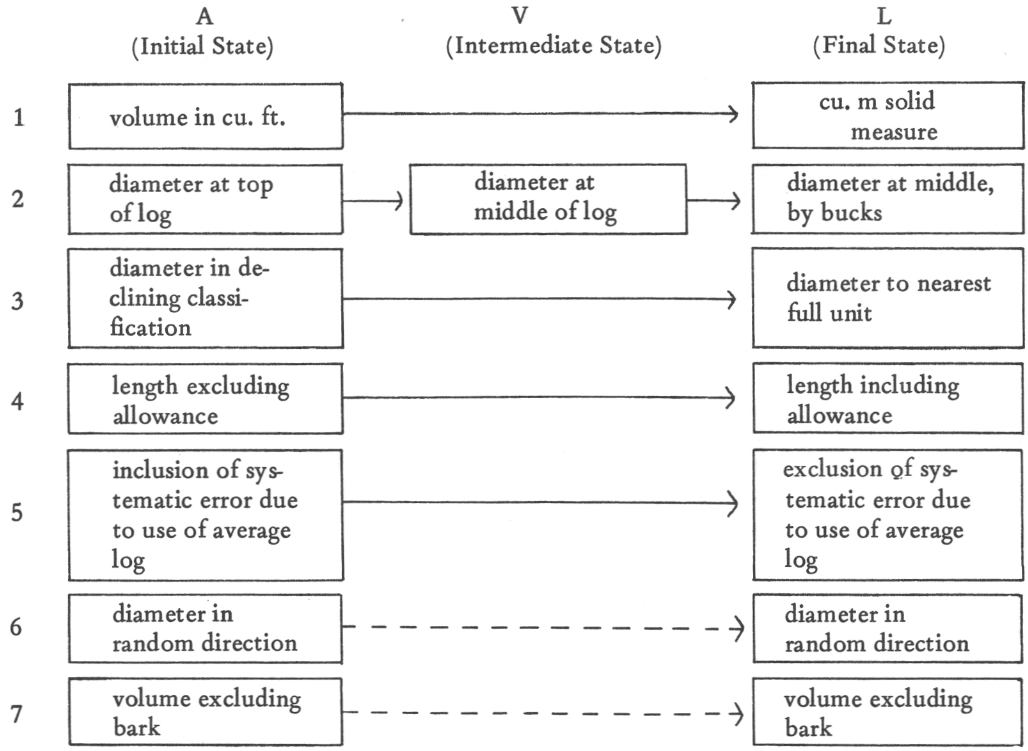

Fig. 1. Model of the calculation system of conversion factors for pine and spruce saw logs in south Finland and spruce saw logs in north Finland.

In process A_1–L_1 cubic feet are converted into cubic metres solid measure by multiplying by 0.028315, the ratio of these measurement units (Tapion Taskukirja 1965, p. 427). Processes A_2–V_2, A_3–L_3 and A_4–L_4 have already been combined into a single conversion factor (ARO & RIKKONEN 1966, pp. 7, 60, 65 and 67). Process V_2–L_2 was carried out with values obtained by graphical adjustment from Table 19 in ARO & RIKKONEN (p. 47). A more detailed review is necessary before process A_5–L_5 can be understood.

The conversion factor and top form factor tables for coniferous saw logs can, in principle, be used in two ways: (1) the technical volume in cubic feet of the lot is converted into solid measure by diameter and length classes; (2) this distribution is not known, and the conversion factor is chosen on the basis of the length and volume of the average log in the lot. In national removal statistics, method (2) must be applied. This leads, however, to a systematic underestimation of the conversion factor. For top form factors, this problem was discussed by ARO & RIKKONEN (1966, pp. 40–41). According to their experiments, the systematic error ranged from –0.5 to –1.5 per cent.

The cause of the error can be traced by simple simulation trials. While the mean volume and mean length of the imaginary lot of logs was kept constant, the range and form of the diameter and length distributions were varied. On the basis of the experiments it was found that, as the range of the diameter distribution of the logs increased, the systematic error grew. The phenomenon can be interpreted if the conversion factor is considered as a function of length and diameter. Dependence on length is approximately linear and on diameter markedly non-linear. The systematic error arising from the use of the average logs is therefore due to the fact that the dependence of the conversion factor on log diameter is not linear as it is for length.

In order to correct this systematic error, the mean diameter distributions of the volumes of the three groups of saw logs were estimated separately. This was done weighting the small-scale sawmill material assembled by HUTTUNEN (1969) with the saw log quantities used in 1966 by the sawmills not included in the industrial statistics; the "practical" material on "large-scale" sawmills (ARO & RIKKONEN 1966 p. 21) was weighted with the quantities entered in the 1966 industrial statistics. The final mean correction coefficients obtained were: pine saw logs, south Finland, 1.030; spruce saw logs, south Finland, 1.041; and spruce saw logs, north Finland, 1.017. These coefficients, as would be expected, exceeded those obtained by ARO & RIKKONEN, since their "practical" material contained no sawmills with an output of under 3 000 stds (1966, p. 19).

The level of the new conversion factors calculated by the author for saw logs is in the largest diameter classes slightly higher and elsewhere the same or slightly lower than that of the conversion factors used previously. The correction factor for the systematic error caused by the use of the average log had not been applied before. This usage raised the level of the conversion factors. On the other hand, this rise was compensated by the introduction of the new top form factors, which reduced the level of the conversion factors in the most common diameter classes (ARO & RIKKONEN 1966, p. 37).

The accuracy of the new conversion factors is difficult to quantify. All phases of the calculation-system model in Fig. 1, apart from process A_1-L_1, produce a potential error in the final conversion factors. The inaccuracy contained in the top form factors (process A_2-V_2) has been commented on in PALO, 1969, pp. 59—60.

The computer could be used in two ways in the search for conversion factors: (1) by programming the tables as they are into the computer's memory, or (2) by estimating the best possible regression equations for determining the variation in the conversion figures, and to program these equations. Alternative (2) was finally selected, since its application required less programming and less computer-memory capacity, while it also made possible the interpolation and extrapolation of the conversion factors. The initial situation for the estimation of the regression equations was the following: (1) the dependent variable was the conversion factor calculated by the method shown in Fig. 1, which converts the technical cubic feet of the relevant saw log assortment into cubic metres; (2) there were two original independent variables: the mean length and volume of the lot of logs.

The method of estimation chosen was selective linear regression analysis. From a preliminary graphical review, it was known that the dependent variable (conversion factor) was as a function of the log length approximately linear, but as a function of the volume non-linear. It also became evident that the independent variables interacted with the conversion factor. Suitable transformations of the variables had to be found before it was possible to estimate effectively with the linear regression model. The aim was maximization of the degree of determination, and minimization of the systematic errors of determination.

An analysis of the structure of conversion factors offered a fruitful basis for hypotheses of apparently serviceable transformations. The top form factors used in process A_2-V_2 of Fig. 1 refer to the ratio between a volume based on the centre diameter of a log and one based on the top diameter. Once the length (l) and volume (v) of the log were known, the corresponding diameter could be obtained from them, $d = 2\sqrt{v/(\pi l)}$. The paraboloid, cone and neiloid are the mathematical bodies most closely approaching the shape of a tree trunk. Since a log is part of a tree trunk, efforts were made to derive the formulas of a truncated paraboloid, cone and neiloid by making certain generalizations concerning the tapering of trees and disregarding the values of the coefficients. When the formulas obtained were compared, according to the structure of top form factors, with the corresponding formula for a cylinder, the following hypothetical transformations were obtained for the independent variables: truncated paraboloid l^2/v, truncated cone $\sqrt{l^3}/v$ and truncated neiloid $\sqrt[3]{l^4}/v$.

The mathematical solution of processes A_3-L_3 and A_4-L_4 in Fig. 1 gave the following hypothetical transformations: 1/l, 1/v, l/v, $\sqrt{l/v}$, and $l/\sqrt{lv}$. From process V_2-L_2, the linear dependence of the conversion factor under estimation on the diameter of the log could be inferred. The transformations $\sqrt{v/l}$

and v/l were chosen to indicate the diameter class.

On the basis of the method by which the conversion factors had been calculated, a number of hypothetical transformations of the independent variation were found. Since the different degrees of the same basic transformation can always be assumed to have a determination potential, 30 transformations derived on the basis of the above hypotheses and the two original independent variables were selected for the final selective regression analysis. The calculation was carried out by computer, using the library program of the selective linear regression analysis. (VÄLIAHO 1964). The results were the following conversion equations for the various saw log assortments:

$$(1)\quad y_1 = 3.16 + 1.39\, l/v - 0.0349(l/v)^2 + 0.202\, l - 5.40/v + 0.00223\, l^3/v - 0.244\sqrt{l^3/v} - 0.225\,(l^3/v)^2\, 10^{-6}$$

$$(2)\quad y_2 = 5.05 - 1.96/v - 1.45\sqrt{l/v} + 0.498(\sqrt{l/v})^3 - 0.0890(l/v)^2 - 0.388(l^2/v)^2\, 10^{-4}$$

$$(3)\quad y_3 = 18.4 + 0.0456\, l - 0.455(lv)^3\, 10^{-7} - 6.50(\sqrt{v/l})^3 - 12.0\sqrt{l/v} + 2.13(\sqrt{l/v})^3 - 0.431(l/v)^2$$

$$(4)\quad y_4 = 0.0433\, l - 0.149(lv)^3\, 10^{-7} + 5.59/v^3 + 14.5\sqrt{v/l} - 4.37(\sqrt{v/l})^3 + 2.19\, l/v - 0.142(l/v)^2 - 9.31$$

Estimated conversation factor, per cent:

y_1 = for spruce saw logs, south Finland

y_2 = for pine saw logs, south Finland

y_3 = for spruce saw logs, north Finland

y_4 = for pine saw logs, north Finland

l = mean length of the logs in ft.

v = mean volume of the logs cu.ft.

The following characteristics to describe the accuracy of equations (1) – (4) were estimated:

Equation	R^2	s	$100s/\bar{y}_i$
y_1	99.8	0.0172	0.41
y_2	99.9	0.0112	0.27
y_3	99.8	0.0158	0.35
y_4	99.8	0.0173	0.41

R^2 = degree of determination

s = standard deviation of determination errors

$\bar{y}_i$ = mean value of y_i

The following are the usual assumptions concerning errors of determination in the estimation of regression models: (1) their mean value equals zero, (2) their distribution is normal, (3) their distribution is random, and (4) the variance is constant in the whole range of variation (e.g. DRAPER & SMITH 1967, p. 86). It could be shown by calculation that assumptions (1) and (2) had apparently not been invalidated. The assumption of normality was tested by the chi-square test. The validity of assumptions (3) and (4) was reviewed graphically.

The regression coefficients were tested by the t test. The coefficient of the variable $1/v^3$ of model (4) differed from zero at a risk of 1.5 per cent. For all the other coefficients the corresponding risk percentage was less than 0.1 per cent.

The conversion function for pine saw logs of north Finland was presented in model (4). The material used consisted of the tables applied in the wood consumption studies of the Forest Research Institute, and the correction presupposed by process $A_5 - L_5$ in Fig. 1 was made by using the coefficient 1.0325.

3. Birch veneer logs

The conversion factors earlier used for birch veneer logs were worked out in 1955–56. They could be renewed after fresh study results were available (NISULA 1967a). Birch veneer logs have usually been measured in Finland in English cubic feet (cu.ft.) (Fig. 2, A), taking the diameter at the middle of the log, including bark, in the thinnest direction, using the declining 0.5 in. classification. No allowance was included in the length on which calculation of volume was based. The present work aimed at compiling a system of calculation by which conversion factors could be estimated to convert, with maximum accuracy, the volumes in cu.ft. of birch veneer logs into true cubic metres solid measure, excluding bark. A model of this calculation system is shown in Fig. 2.

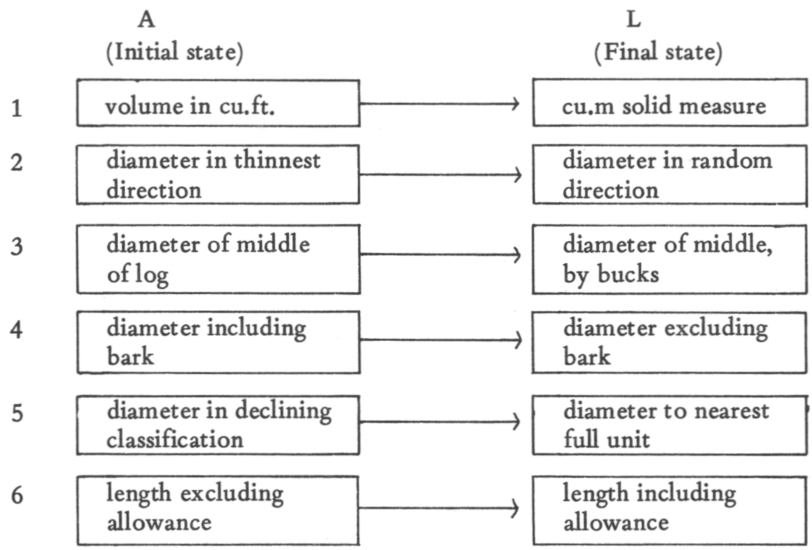

Fig. 2. Model of calculation system for conversion factors of birch veneer logs.

In process $A_1 - L_1$ in Fig. 2, the volume in cu.ft. of A_1 is converted into cu.m solid measure by multiplying by 0.028315 (see p. 3). In process $A_2 - L_2$, the systematic error arising from the measurement of the thinnest diameter is corrected by the coefficient 1.046. In process $A_3 - L_3$, the volume based on the diameter of the middle of the log is converted into a volume measured for four–foot bucks using the coefficient 1.020. From the volume including bark, the volume excluding bark is obtained by coefficient 0.867 in process $A_4 - L_4$ (NISULA 1967a, pp. 26–28, 34). The systematic error arising from the diameter measured with the half-inch declining classification in process $A_5 - L_5$ is corrected with the correction coefficient (k_2) obtained from the following formula:

(5) $$k_2 = [(d+0.25)/d]^2$$

k_2 = correction coefficient
d = log diameter in inches

The length of the mean allowance of veneer logs in NISULA's (1967a, p. 35) material was 5.8 in. (= 0.48 ft.). In process $A_6 - L_6$ the volume excluding allowance is converted into volume including allowance by using the formula:

(6) $$k_1 = (l+0.48)/l$$

k_1 = correction coefficient
l = length of log in feet

When all the processes in Fig. 2 were combined, the following equation was obtained for estimation of the conversion factor for veneer logs:

$$(7) \quad y = [0.0262(l+0.48)(d+0.25)^2]/ld^2$$

y = conversion factor of veneer logs to be estimated
d = diameter of log in inches
l = length of log in feet

On the other hand, d can be expressed as the function of the knoun variables l and v (log volume):

$$(8) \quad d = 13.54\sqrt{v/l}$$

d = diameter of log in inches
v = volume of log in cubic feet
l = length of log in feet

When the value d of equation (8) is inserted in equation (7), the estimator of the conversion factor of birch veneer logs obtained is:

$$(9) \quad y = 0.0262+0.0126/l+0.893\cdot10^{-5}(l/v) +0.00967\sqrt{l/v} + 0.000464/\sqrt{lv}$$

y = estimated conversion factor for birch veneer logs
l = length of log in feet
v = volume of log in cubic feet

In this way, a conversion function (9) for birch veneer logs was derived completely theoretically, thus having a one hundred per cent degree of determination. The form of this model is reminiscent of the regression models estimated for coniferous saw logs by the linear regression analysis above. The conversion factors calculated using model (9) are 5–7 per cent higher than those used previously. The range of the new conversion factors is 0.0283–0.0293, of the old 0.026–0.027, and of the conversion factors calculated by ARO (1965, p. 261), 0.028–0.029. The conversion factors calculated by ARO covered seven log length and diameter classes. He based his calculations on the studies by PÖNTYNEN (1933) and PUTKISTO (1947).

4. Birch saw logs

The conversion factors previously used by the Forest Research Institute for birch saw logs were based on investigations by PÖNTYNEN (1933). The conversion factor table calculated for birch saw logs by ARO (1965, p. 261) was based on a combination of the results obtained by PÖNTYNEN (1933) and PUTKISTO (1947). In the present study, a regression equation was estimated on the basis of ARO's conversion-figure material:

$$(10) \quad y = 7.00+373/l^3+0.0597l^2/v - 0.342\cdot 10^{-4}(l^4/v)-3.45\sqrt{l/v}-2.73(\sqrt{v/l})^3 + 5.73/v^2$$

y = estimated conversion factor for birch saw logs in per cent
l = length of log in feet
v = volume of log in cubic feet

The degree of determination (R^2) of the equation was 99.1 per cent, the standard deviation of the estimated variable 0.496, and the variation coefficient 1.22 per cent. The chi-square test did not suggest that the errors of determination in the model did not have a normal distribution. The random character of the errors of determination, on graphical inspection, was good. The main cause of the low degree of determination compared with that for coniferous saw logs was that the initial material for the estimation had an accuracy of only two significant digits. It was decided to re-check the conversion factors for birch saw logs on the basis of newer initial material (NISULA 1967a).

The initial state for the conversion of birch saw logs was the following: the diameter was measured at the top of the log, including bark, in random direction, using the half-inch declining classification; the volume in cubic feet was measured without allowance. In practice, the model of the calculation system of the conversion factors of birch saw logs differed from the model in Fig. 2 as follows: instead of the correction of the diameter measured in the thinnest direction, the top diameter converted into the diameter at the middle was inserted in process A_2—L_2; and the mean allowance of birch saw logs was 5.4 inches or 0.45 feet (NISULA 1967a, p. 35, and ARO & RIKKONEN 1966, p 7). Without this multiplication by the top form factors, the following conversion equation could be derived theoretically for birch saw logs:

$$(11)\quad y_1 = 0.0250+0.00831/l+0.851\cdot 10^{-5}(l/v) +0.000923\sqrt{l/v}+0.000416/\sqrt{lv}$$

y_1 = estimated conversion factor for birch saw logs before multiplication by top form factor
l = length of log in feet
v = volume of log in cubic feet

The top form factor material required for the estimation of the conversion factors for birch saw logs was obtained from the original nomogram presented by NISULA (1967a, p. 46) as a function of log length (l) and the log volume/length ratio (v/l). From this material the following equation for the top form factors of birch saw logs was estimated by means of selective linear regression analysis:

$$(12)\quad y_2 = 0.898 + 0.000648(l/v)^3 -0.000386 (l^3/v) + 0.0173\sqrt{l^3/v} + 0.799 \cdot 10^{-5} (l^4/v)$$

y_2 = top form factor of birch saw logs
l = length of log in feet
v = volume of log in cubic feet

R^2 = 99.4 = degree of determination
s = 0.00315 = standard deviation of determination errors
100 $s/\bar{y}_2$ = 0.026
$\bar{y}$ = mean value of y_2

The analysis of errors of determination suggested that apparently none of the four conditions made for the determination errors of regression analysis had been invalidated. In the t test, all the regression coefficients differed from zero by a maximum risk of 0.1 per cent.

The final model for estimating the conversion factors of birch saw logs was obtained by multiplying equations (11) and (12):

$$(13)\quad y = 0.0224+0.00746/l+0.000128(l^2/v) -0.958\cdot 10^{-5}(l^3/v) + 0.200\cdot 10^{-6}(l^4/v)+0.0000162(l/v)^3 + 0.000973\sqrt{l/v} -0.356\cdot 10^{-6}(l^3/v)\sqrt{l/v} + 0.737\cdot 10^{-8}(l^4/v)\sqrt{l/v} + 0.000432\sqrt{l^3/v}$$

y = conversion factor of birch saw logs (diameter at the top, including bark)
l = length of log in feet
v = volume of log in cubic feet

In conclusion, it may be said that there were two interesting theoretical phases in developing the conversion functions for logs. First, the nesessary transformations of the independent variables could be, in the main, derived on the basis of the structure of the conversion factors studied. Second, conversion functions (9) and (11) were derived for veneer logs and birch saw logs by a completely theoretical route, and their shape corroborated the choice of linear regression analysis for the model type used in the other cases.

5. Pulpwood

The conversion factors previously used by the Forest Research Institute for coniferous pulpwood were mainly based on the publication of SAARI *et al.* 1939. The material for the pile density studies on which the publication was based had been collected only from south Finland (ARO 1958, p. 7). Pulpwood conversion factors are obtained by multiplying the pile density by the percentage of the corresponding wood volume excluding bark. The present aim was to convert the quantities expressed in cu.m piled measure, variously barked and of different lengths, into cu.m solid measure excluding bark. The pile densities of coniferous pulpwood in south Finland could be checked with the aid of two more recents studies (HEMMI 1966 and RIKKONEN 1968) for log lengths of 1.8–2.3 metres. For these lengths, they confirmed the earlier results from the 1920s and 1930s. The percentage of the wood excluding bark in the pine pulpwood of south Finland was calculated as the unweighted mean value from three studies (ARO 1965, HAKKILA 1967, RIKKONEN 1968), and the percentage of barking waste was calculated from RIKKONEN's (1968) material. With a selective linear regression analysis, the following equation was estimated for the conversion factor of the p i n e p u l p w o o d in s o u t h F i n l a n d:

(14) $y = 0.174 - 0.0461\sqrt[5]{l^2} + 0.00687\,k$

y = conversion factor of pine pulpwood in south Finland
l = length of bolt in decimetres
k = degree of barking: including bark = 88; partly barked = 98

The percentages of wood excluding bark and of barking waste in the s p r u c e p u l p w o o d of s o u t h F i n l a n d were determined as for pine pulpwood above. Besides the pile-density studies mentioned, the results published by ARO (1959) concerning spruce pulpwood were available. The old and the new pile densities showed good agreement for the 4-metre long bolts, while the pile density of the 2-m bolts seemed to have diminished. Regression equations were calculated for the conversion factors:

(15) $y = 0.705 - 0.0160\sqrt{l}$

y = conversion factor for spruce pulpwood including bark in south Finland
l = length of bolt in decimetres

(16) $y = 0.795 - 0.0184\sqrt{l}$

y = conversion factor for partly barked spruce pulpwood in south Finland
l = length of bolt in decimetres

The percentage of wood excluding bark in the coniferous pulpwood in north Finland was estimated on the basis of three sources (ARO 1965, PERTOVAARA 1960 and 1964) and the percentage of barking waste from PERTOVAARA (1960). Results of studies of pile densities were available for pine-pulpwood lengths of 2.0–4.8 metres (ARO 1958 and 1959; HEMMI 1965, 1966 and 1967; MAKKONEN 1958; PERTOVAARA 1958, 1960 and 1964). A regression equation was estimated for conversion factors of p i n e p u l p w o o d:

(17) $y = 0.0534 - 0.00165 l + 0.00696 k$

y = conversion factor for pine pulpwood in north Finland
l = length of bolt in decimetres
k = degree of barking: including bark = 85; partly barked = 98

The pile-densities of s p r u c e p u l p w o o d i n n o r t h F.i n l a n d could be calculated for the lengths of 2.0–4.5 metres from the above sources on pile density of pine pulpwood (excluding MAKKONEN). The following regression equation was calculated for the conversion factor of spruce pulpwood:

(18) $y = 0.0643 - 0.00196 l + 0.00698 k$

y = conversion factor for spruce pulpwood in north Finland
l = length of bolt in decimetres
k = degree of barking: including bark = 84; partly barked = 98

The percentage of wood excluding bark in b i r c h p u l p w o o d was calculated from the following sources: ARO (1965); HAKKILA (1967); ARO *et al.* (1958); and HEISKANEN & KOIVULEHTO (1964). The barking loss was estimated from the last two studies. The calculation of the pile density of birch pulpwood was based, as far as the length 2.0–2.4 metres was concerned, on the papers of HEISKANEN & KOIVULEHTO (1964), MAKKONEN (1958, 1960 and 1965) and NISULA (1967b), and for the length 4.4 metres on the paper of HEISKANEN & KOIVULEHTO (1964). The following three equations were estimated for the conversion factors of birch pulpwood:

(19) $y = 0.717 - 0.00341\,l$

(20) $y = 0.625 - 0.00300\,l$

(21) $y = 0.595 - 0.00282\,l$

y = conversion factor for birch pulpwood:
(19) whole country, partly barked
(20) south Finland, including bark
(21) north Finland, including bark
l = length of bolt in decimetres

It may be concluded from the above functions for pulpwood conversion that the risk of error in the empirical material on which they are based seems biggest in two respects. First, results of pile-density studies concerning logs longer than 4 metres are few, and hence it is difficult to obtain an accurate idea on the form of the function. Second, the percentages of wood excluding bark, calculated from the volumes of both unbarked and partly barked wood, vary considerably from one study to another, especially for coniferous wood. Primarily for these reasons the conversion functions for pulpwood must be looked upon as approximations, which should be checked as soon as new fundamental study results are available.

Conversion of the commercial measurement units of roundwood into commensurate units has attracted little attention up to now in published forest statistics and in the studies based on them, although in many cases the risk of error arising from the use of obsolete conversion factors has been evident, even in the interpretation of the final results. In recent years, the technology of roundwood harvesting has undergone rapid changes in Finland. For this reason, the study results on which conversion factors are based should be checked more often than they have been up to now, and, as far as possible, forecast models concerning future changes should be built. When this kind of fundamental research is planned, the information required to check the conversion functions of the present study should be taken into consideration, in order that they may later be up-dated in the best possible way.

REFERENCES

ARO, PAAVO. 1958. Pohjois-Suomen 2 m kuusi- ja mäntypaperipuiden pinotiheydestä, kuorimishäviöstä ja kuutiosuhteista. Referat: Über den Festgehalt der Stösse, den Entrindungsverlust und die Kubikmassenverhältnisse von 2 M Fichten – und Kiefernzellstoffholz aus Nord-Finnland. CIFF 50.8. Helsinki.

ARO, PAAVO. 1959. Nippujen kuutioimistaulukot 2 m ja 4 m kuusipaperipuille. Referat: Kubiktabellen für Bündel von 2 m und 4 m Fichtenzellstoffholz. CIFF 51.5. Helsinki.

ARO, PAAVO. 1965. Puutavaran kuutioiminen Tapion taskukirja, pp 253–272. Kirjayhtymä. Helsinki.

ARO, PAAVO & KORPELA, TAPIO & NISULA, PENTTI. 1958. Tutkimuksia kuusiohutpuun kuorimishäviöstä. Referat: Untersuchungen über den Entrindungsverlust bei Fichtendünnholz und Birkenzellstoffholz. CIFF 50.2. Helsinki.

ARO, PAAVO & RIKKONEN, PENTTI. 1966. Havutukkien latvamuotoluvut. Summary: The form factors of softwood saw logs. CIFF 61.7. Helsinki.

DRAPER, NORMAN & SMITH, HARRY. 1967. Applied regression analysis. John Wiley & Sons, Inc. U.S.A.

HAKKILA, PENTTI. 1967. Vaihtelumalleja kuoren painosta ja painoprosentista. Summary: Variation patterns of bark weight and bark percentage by weight. CIFF 62.5. Helsinki.

HEISKANEN, VEIJO & KOIVULEHTO, PENTTI. 1964. Tutkimus 2.2 m ja 4.4 m koivupaperipuun pinotiheydestä ja kuorimishukasta VK-16- kuorimiskoneella kuorittaessa. Summary: A study of the pile-density of 2.2-meter and 4.4-meter birch pulpwood and their barking losses when barking with a VK-16-barker. Pienpuualan toimikunta. Julkaisu 170. Mimeographed. Helsinki.

HEMMI, LAURI. 1965. Paperipuun pinotiheysmittauksia Kemijoella 1965. Uittoteho r.y. tiedoituksia N:o 214. Mimeographed. Rovaniemi.

HEMMI, LAURI. 1966. Eräitä tutkimustuloksia mänty- ja kuusipaperipuun tilavuus- ja painosuhteista sekä niiden vaikutuksesta massan saantoon Etelä- ja Pohjois-Suomessa. Uittoteho r.y. Oy. Keskuslaboratorio. Mimeographed.

HEMMI, LAURI. 1967. Jatkotutkimus paperipuun pinotiheyksistä Kemijoella 1967. Uittoteho r.y. tiedoituksia N:o 235. Mimeographed. Rovaniemi.

HUTTUNEN, TERHO. 1969. Länsi-Suomen havusahatukkien koko ja laatu v. 1966. The size and quality of coniferous sawlogs in western Finland in 1966. FF 56. Helsinki.

MAKKONEN, OLLI. 1958. Pinotiheystutkimuksia. Summary: Pile-density studies. Pienpuualan toimikunta N:o 45. Metsäteho. Helsinki.

MAKKONEN, OLLI. 1960. Kuorimattomien 2.4-metristen koivupaperipuiden ja 2-metristen koivupolttorankojen pinotiheysmittauksia. Summary: Pile density of unbarked 2.4-metre birch pulpwood and unbarked 2-metre birch fuelwood. Metsätehon tiedotus 173. Helsinki.

MAKKONEN, OLLI. 1965. Koivupaperipuiden mutkaisuuden vaikutuksesta pinotiheyteen. Summary: On the effect of the curviness of birch pulpwood on the pile density. Metsätehon tiedotus 241. Helsinki.

NISULA, PENTTI. 1967a. Tutkimuksia vaneritukkien ja sorvipölkkyjen kuutio- ja painosuhteista. Summary: Studies on the relationships between the volume and weight in veneer logs and bolts for rotary cutting. CIFF 63.1. Helsinki.

NISULA, PENTTI. 1967b. Koivupaperipuun pinotiheydestä ja kuutiosuhteista. Summary: On the pile density and volume of birch pulpwood. CIFF 62.7. Helsinki.

PALO, MATTI. 1964. Markkinapuun alueittaiset hankintamäärät v. 1962. Ennakkoselostus. Summary: Removals of commercial roundwood in Finland by district in 1962. Preliminary Report. FF 2. Helsinki.

PALO, MATTI. 1969. Ostajaontaan perustuva hakkuutilasto. Summary: Removal statistics based on a sample of buyers. CIFF 68.1. Helsinki.

PERTOVAARA, H. 1958. Pinotiheysmittauksista Tornionjoen Uittoyhdistyksen alueella. Uittoteho r.y. Mimeographed. Kemi.

PERTOVAARA, H. 1960. Pitkän pinotavaran pinotiheysmittauksista Pohjois-Suomessa. Uittoteho r.y. tiedoituksia N:o 183. Mimeographed. Rovaniemi.

PERTOVAARA, H. 1964. Tasapituisen paperipuun pinotiheys- ja kuutiointimittauksia Pohjois-Suomessa. Uittoteho r.y. tiedoituksia N:o 209. Mimeographed. Rovaniemi.

PUTKISTO, KALLE. 1947. Tutkimuksia vanerikoivujen hankinnasta 1: koivupölkkyjen kuutiosuhteista. Metsätehon julkaisuja N:o 4. Helsinki.

PÖNTYNEN, V. 1933. Koivutukkien todelliset kuutiomäärät ja latvamuotoluvut. Summary: The actual volume and form factors of birch logs. CIFF 14.1. Appendix 4. Helsinki.

RIKKONEN, PENTTI. 1968. Havupaperipuiden kuorimishäviö VK-16-koneella kuorittaessa. Summary: The barking loss of coniferous pulpwood barked with VK-16 machines. FF 41. Helsinki.

SAARI, E. & KELTIKANGAS, V. & VUOTI, E. 1939. Kuusi- ja mäntypaperipuitten pinotiheys ja kuorimishukka. Metsätaloudellinen Aikakauslehti. Helsinki.

SAARI, EINO & PÖNTYNEN, V. & ARO, PAAVO. 1929. Kiintomittataulukkoja. Tapio.

TAPION TASKUKIRJA 1965. Kirjayhtymä. Helsinki.

VÄLIAHO, HANNU. 1964. Regressioanalyysin suorittaminen tietokoneella. Tilastomatematiikan perusteet II, pp. 85–87. Insinöörijärjestöjen koulutuskeskus. Täydennyskoulutuskurssi N:o 46.

CIFF = Communicationes Instituti Forestalis Fenniae

FF = Folia Forestalia

No 45 Pentti Koivisto: Etelä- ja Pohjois-Karjalan, Itä-, Etelä- ja Pohjois-Savon sekä Keski-Suomen koivuvarat.
Birch resources in Forestry Board Districts of Etelä- and Pohjois-Karjala, Itä-, Etelä- and Pohjois-Savo and Keski-Suomi. 2,—
No 46 Terho Huttunen: Suomen puunkäyttö vuonna 1966, ennakkotietoja vuodelta 1967 ja ennuste vuodelle 1968.
Wood utilization in Finland in 1966, preliminary data for 1967 and forecast for 1968 3,—
No 47 Metsätilastoa 1950—67.
Forest Statistics of Finland 1950—67. 4,—
No 48 Tarmo Peltomäki ja Heikki Veijalainen: Kiinteistöjen käyttämän lämpöenergian ominaiskulutus.
Specific consumption of thermal energy utilized by real estates. 2,50
No 49 Seppo Ervasti ja Kullervo Kuusela: Suomen metsätase vuosina 1953—66.
Forest balance of Finland in 1953—66. 2,—
No 50 Kalevi Asikainen: Tasausvara ja sahatavaran tasaus.
On the trimming allowance and trimming. 2,—
No 51 Teuri J. Salminen: Havusahatukkien kuutiointi kuoren päältä mitatun läpimitan perusteella.
On cubing coniferous saw logs on the basis of measurements taken on the bark. 2,—
No 52 Olli Makkonen: Paperipuiden pituuden vaikutuksesta runkojen hyväksikäyttöön minimiläpimitan ollessa 5 cm.
On the influence of the length of pulpwood bolts on the degree of utilization of tree stems when the minimum diameter is 5 cm. 2,—
No 53 Simo Poso, Christian Keil and Tapani Honkanen: Comparison of film-scale combinations in examining some stand characteristics from aerial photographs.
Eri filmi-mittakaavayhdistelmät eräiden metsikkötunnusten ilmakuvatulkinnassa. 2,50
No 54 Pertti Veckman: Suomen piensahat vuosina 1965 ja 1967.
Small sawmills in Finland in 1965 and 1967. 2,50
No 55 Kimmo Paarlahti ja Kalevi Karsisto: Koetuloksia kaliummetafosfaatin, raakafosfaatin, hienofosfaatin ja superfosfaatin käyttökelpoisuudesta suometsien lannoituksessa.
On the usability of potassium metaphosphate, raw phosphate, rock phosphate and superphosphate in fertilizing peatland forests. 1,50

1969 No 56 Terho Huttunen: Länsi-Suomen havusahatukkien koko ja laatu vuonna 1966.
The size and quality of coniferous sawlogs in western Finland in 1966. 1,50
No 57 Metsäntutkimuslaitoksen päätös puutavaran mittauksessa käytettävistä muuntoluvuista ja kuutioimistaulukoista.
Skogsforskningsinstitutets beslut beträffande omvandlingskoefficienterna och kuberingstabellerna, som används vid virkesmätning. 28,80
No 58 Paavo Tiihonen: Puutavaralajitaulukot 2. Maan eteläpuoliskon mänty, kuusi ja koivu. 2,50
No 59 Paavo Tiihonen: Puutavaralajitaulukot 3. Männyn ja kuusen uudet paperipuutaulukot. 2,50
No 60 Paavo Tiihonen: Puutavaralajitaulukot 4. Maan pohjoispuoliskon mänty ja kuusi. 2,—
No 61 Matti Aitolahti ja Olavi Huikari: Metsäojien konekaivun vaikeusluokitus ja hinnoittelu.
Classification of digging difficulty and pricing in forest ditching with light excavators. 1,—
No 62 Kullervo Kuusela ja Alli Salovaara: Etelä-Pohjanmaan, Vaasan ja Keski-Pohjanmaan metsävarat vuonna 1968.
Forest resources in the Forestry Board Districts of Etelä-Pohjanmaa, Vaasa and Keski-Pohjanmaa in 1968. 3,—
No 63 Arno Uusvaara: Maan ja metsän omistus Suomessa v. 1965 alussa ja sen kehitys v 1957—65.
Land and forest ownerships in Finland 1965 and their development during 1957—65. 2,50
No 64 Timo Kurkela: Haavanruosteen esiintymisestä Lapissa.
Leaf rust on aspen in Finnish Lapland. 1,—
No 65 Heikki Ravela: Metsärunko-ojien mitoitus.
Dimensioning of forest main ditches. 1,50
No 66 Matti Palo: Regression models for estimating solid wood content of roundwood lots.
No 67 Terho Huttunen: Suomen puunkäyttö, poistuma ja metsätase vuosina 1967—69.
Wood consumption, total drain and forest balance in Finland in 1967—69. 2,50
No 68 Lauri Heikinheimo, Seppo Paananen ja Hannu Vehviläinen: Stumpage and contract prices of pulpwood in Norway, Sweden and Finland in the felling seasons 1958/59—1968/69 and 1969/70. 2,50
No 69 U. Rummukainen ja E. Tanskanen: Vesapistooli ja sen käyttö.
A new brush-killing tool and its use. 1,—
No 70 Metsätilastollinen vuosikirja 1968.
Yearbook of forest statistics 1968. 6,—
No 71 Paavo Tiihonen: Rinnankorkeusläpimittaan ja pituuteen perustuvat puutavaralajitaulukot. 1,—
No 72 Olli Makkonen ja Pertti Harstela: Kirves- ja moottorisahakarsinta pinotavaran teossa.
Delimbing by axe and power saw in making of cordwood. 2,50
No 73 Pentti Koivulehto: Juurakoiden maasta irroittamisesta.
On the extraction of stumps and roots. 1,50

Luettelo jatkuu 4. kansisivulla

No 74 Pertti Mikkola: Metsähukkapuun osuus hakkuupoistumasta Etelä-Suomessa.
Proportion of wastewood in the total cut in southern Finland. 1,50

No 75 Eero Paavilainen: Tutkimuksia levitysajankohdan vaikutuksesta nopealiukoisten lannoitteiden aiheuttamiin kasvureaktioihin suometsissä.
Influence of the time of application of fast-dissolving fertilizers on the response of trees growing on peat. 2,—

1970 No 76 Ukko Rummukainen: Tukkimiehentäin, Hylobius abietis L., ennakkotorjunnasta taimitarhassa.
On the prevention of Holybius abietis L. in the nursery. 1,50

No 77 Eero Paavilainen: Koetuloksia suopeltojen metsittämisestä.
Experimental results of the afforestation of swampy fields. 2,—

No 78 Veikko Koskela: Havaintoja kuusen, männyn, rauduskoivun ja siperialaisen lehtikuusen halla- ja pakkaskuivumisvaurioista Kivisuon metsänlannoituskoekentällä.
On the occurrence of various frost damages on Norway spruce, Scots pine, silver birch and Siberian larch in the forest fertilization experimental area at Kivisuo. 2,—

No 79 Olavi Huikari—Pertti Juvonen: Työmenekki metsäojituksessa.
On the work input in forest draining operations. 1,50

No 80 Pertti Harstela: Kasausajan ja valtimonlyöntitiheyden sekä tehollisen sahausajan määrittäminen järjestettyjen kokeiden, pulssitutkimuksen ja frekvenssianalyysin avulla.
Determination of pulse repetition frequency and effective sawing time with set tests pulse study and frequency analysis. 1,50

No 81 Sulo Väänänen: Yksityismetsien kantohinnat hakkuuvuonna 1968—69.
Stumpage prices in private forests during cutting season 1968—69. 1,00

No 82 Olavi Huuri, Kaarlo Kytökorpi, Matti Leikola, Jyrki Raulo ja Pentti K. Räsänen: Tutkimuksia taimityyppiluokituksen laatimista varten. I Vuonna 1967 metsänviljelyyn käytettyjen taimien morfologiset ominaisuudet.
Investigations on the basis for grading nursery stock. I The morphological characteristics of seedlings used for planting in the year 1967. 1,50

No 83 Ole Oskarsson: Pluspuiden fenotyyppisessä valinnassa sovellettuja valinnan asteita.
Selection degrees used in the phenotypic selection of plus trees. 1,50

No 84 Kari Keipi ja Otto Kekkonen: Calculations concerning the profitability of forest fertilization.
Laskelmia metsän lannoituksen edullisuudesta.

No 85 S.—E. Appelroth — Pertti Harstela: Tutkimuksia metsänviljelytyöstä I. Kourukuokka, kenttälapio, taimivakka, taimilaukku sekä istutuskoneet Heger ja LMD-1 istutettaessa kuusta peltoon.
Studies on afforestation work I. The use of semi-cirular hoe, the field spade, plant basket, plant bag and the Heger and LMD-1 tree planteers in plantink spruce in fields.

Myynti — Available for sale at: Valtion painatuskeskus, Annankatu 44, Helsinki 10, p. 645 121
Merkintä O D C tarkoittaa metsäkirjallisuuden kansainvälistä Oxford-luokitusjärjestelmää

17507—69 Valtion painatuskeskus