Timber Measurement

A Field Guide

by P N Edwards

Forestry Commission
Booklet 49

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Contents

Units used in forestry

Linear measurements		
cm	centimetre	0.01 metre
m	metre	
km	kilometre	1 000 metres
Area measurements		
m^2 or sq m	square metre	
ha	hectare	10 000 sq m
Volume measurement		
m^3 or cu m	cubic metre	1 000 litres
Weight measurement		
	tonne	1 000 000 grammes

Constants

π is 3.1415927

1 m^3 of water weighs 1 tonne.

Introduction

This booklet is designed purely for field use. It assumes some knowledge of, and training in, forest measurement procedures which are more fully described in the *Forest Mensuration Handbook* by G. J. Hamilton, and the reader is referred to this publication for further information. However, the present booklet contains all the mensurational information which may be needed *in the forest* for measuring both standing trees and felled timber.

There are three sections, all based on the information in the *Forest Mensuration Handbook*. The general section is intended as a reference section, and includes definitions of various terms, the conventions used in forestry in Britain, and the basic measurement methods. The section on standing timber includes specific methods for a variety of possible situations, which makes the booklet easier to use although it has led to some duplication. It is hoped that this section will help to standardize the measurement of standing timber, and that negotiations will be simpler if both sides can agree, for example, that the volume should be estimated using method B6. The section on felled timber outlines the methods for measuring both individual logs and stacks of logs.

Acknowledgements

Thanks are due to the many people who have helped with criticisms and ideas, but particularly to J. M. Christie for his valuable assistance, and to G. J. Hamilton, whose book *Forest Mensuration Handbook* was the basis for this field booklet.

Timber Measurement — General

Measuring length and height

All lengths should be measured in metres. They are conventionally rounded down to the nearest tenth of a metre for lengths up to 10 m, and to the nearest whole metre for lengths greater than 10 m. When greater accuracy is required, lengths greater than 10 m can be rounded down to the nearest tenth of a metre.

The *length* of a piece of timber should be measured with a tape following the curvature of the log.

The *total height* of a standing tree is the vertical distance from the base of the tree to the uppermost point (tip). The total height of felled trees is the straight line distance from the base to the tip.

The total height of young standing trees can be measured with graduated poles. The total height of felled trees should be measured with a tape. The total height of other trees should be measured with a hypsometer or clinometer, and the instructions supplied with the instrument should be followed. Each tree should ideally be measured from both sides, and the two measurements averaged. The distance of the observation points from the tree should be in the region of 1 to 1.5 times the height of the tree.

The *timber height* of a tree (or the *timber length*) is the distance from the base of the tree to the lowest point on the main stem where the diameter is 7 cm overbark. In hardwoods and occasionally in conifers this point may alternatively be the 'spring of the crown', i.e. the lowest point at which no main stem is distinguishable. It should be measured in exactly the same way as total height.

The *top height* of a stand is the expected value of the average of the total heights of a number of 'top height trees' in the stand, where a 'top height tree' is the tree of largest breast height diameter in a 0.01 ha sample plot. This is not necessarily the tallest tree. Table 1 gives the likely minimum number of trees required to give an adequate estimate of top height.

Table 1 Number of top height trees

Area of stand (ha)	Uniform crop	Variable crop
0.5–2	6	8
2–10	8	12
Over 10	10	16

The *mean height* of a stand is the average total height of all the trees in the stand. It can be estimated from the top height of a stand (see *Forest Mensuration Handbook*, Table 21, p. 146) but the relationship varies with the type of thinning.

Further information is given in the *Forest Mensuration Handbook*, Part II, p. 19, and Part V, Chapter 4, pp. 143–146.

Measuring diameter

All diameters should be measured in centimetres. Diameters of individual trees are conventionally rounded down to the nearest whole centimetre. Mean diameters may be recorded to the nearest whole centimetre or to the nearest tenth of a centimetre if required.

Diameters are normally measured with a special tape marked in cm diameter, known as a girthing tape, which is placed round the circumference of the tree or log. Girthing tapes which are marked in rounded down 1 cm diameter classes are available. The zero point on all these tapes is the outside edge of the D ring. Diameters can also be measured with calipers, while the diameters of stumps and of the ends of logs are usually measured with a ruler.

The *breast height point* is the point on the tree which is 1.3 m above ground level. On sloping ground, this is the ground level on the upper side of the tree, while on leaning trees on level ground, this is the ground level on the underside of the tree.

The *dbh* is the diameter at the breast height point. Trees with a dbh of less than 7 cm are assumed to have no volume and so are conventionally classified as 'unmeasurable'.

The *mean diameter* of a stand or of a group of trees is the diameter of the tree of mean basal area, which is the same as the quadratic mean of the dbhs of all the trees. Unmeasurable trees are normally excluded from this calculation, but if they are included this should be clearly stated. The mean diameter can be calculated as follows:

1. Using the basal area table on page 9
   a. Convert each dbh into a basal area using Table 2.
   b. Add all the basal areas together.
   c. Divide by the number of trees, to give the mean basal area.
   d. Convert this to the mean dbh using Table 2.
2. Using a calculator which has a square root key
   a. Square each dbh.
   b. Add all the squared values together.
   c. Divide by the number of trees, to give the mean squared dbh.
   d. Calculate its square root, which is the mean dbh.
3. Using a local volume table or a tariff number as described on p. 45.

Or the mean diameter can be estimated by Weise's rule[1], which should not be used for accurate work, but only for a quick check.

a. List all the dbhs in ascending order of 1 cm classes.
b. Work out 40 per cent (2/5) of the number of trees.
c. Count up the list of dbhs starting with the largest dbh until 40 per cent of the trees have been counted.
d. The dbh class of the last counted tree is approximately the mean dbh class.

Further information on diameter is given in the *Forest Mensuration Handbook*, Part II, pp. 17–18.

Table 2 Basal areas

dbh or diameter (cm)	Basal area or cross-sectional area (sq m)	dbh or diameter (cm)	Basal area or cross-sectional area (sq m)
7	0.0038	34	0.091
8	0.0050	35	0.096
9	0.0064	36	0.102
10	0.0079	37	0.108
11	0.0095	38	0.113
12	0.0113	39	0.119
13	0.0133	40	0.126
14	0.0154	41	0.132
15	0.018	42	0.139
16	0.020	43	0.145
17	0.023	44	0.152
18	0.025	45	0.159
19	0.028	46	0.166
20	0.031	47	0.173
21	0.035	48	0.181
22	0.038	49	0.189
23	0.042	50	0.196
24	0.045	51	0.204
25	0.049	52	0.212
26	0.053	53	0.221
27	0.057	54	0.229
28	0.062	55	0.238
29	0.066	56	0.246
30	0.071	57	0.255
31	0.075	58	0.264
32	0.080	59	0.273
33	0.086	60	0.283

[1]Maw, P. T. (1909). *The Practice of Forestry*, pp. 430–431, Walter and Walter.

Measuring basal area

The *basal area* of an individual tree is the cross-sectional area of the tree at its breast height point.

$$BA = \frac{\pi \times dbh^2}{40\,000}$$

where BA = basal area in sq m
dbh = diameter at breast height in cm

The *basal area of a stand* is the sum of the basal areas of all the trees in the stand.

All basal areas should be recorded in square metres, or square metres per hectare, to two or three significant figures as required.

The basal area of a stand can be estimated in two ways:

1. Using a relascope
   a. Choose the number of sample points, using Table 3 as a rough guide. Select this number of points, preferably systematically or with a point sampling grid on the map, throughout the area being assessed. (See note about selection of plots in mixtures.) Each point should be at least the minimum distance from the edge of the area given in Table 4 below.

Table 3 Number of relascope sweeps

Area (ha)	Uniform crop	Variable crop
0.5–2	12	16
2–10	16	24
Over 10	20	32

Table 4 Minimum distances (in metres) of sample points from edge of stand

Maximum likely dbh of trees (cm)	Relascope factor	
	2	0.5
20	7	14
30	11	21
40	14	28
50	18	35
60	21	42
70	25	49
80	28	56

b. At each point, do a 360° sweep with the relascope, and record the number of trees counted. Only trees with a dbh of at least 7 cm should be counted. If an estimate of the basal area of only part of the stand is required, e.g. marked trees, then only these trees should be counted. Note that accurate use of a relascope requires practice.
c. If the point is on sloping ground, multiply the count by the secant of the angle of slope, as given in Table 5.

Table 5 Slopes

Angle of slope (degrees)	Correction factor (secant)	% Slope (tangent x 100)
5	1.004	8.8
7½	1.009	13
10	1.015	18
12½	1.024	22
15	1.035	27
17½	1.049	32
20	1.064	36
22½	1.082	41
25	1.10	47
30	1.15	58
35	1.22	70
40	1.31	84
45	1.41	100
50	1.56	119
55	1.74	143
60	2.00	173

d. Work out the average count, and multiply this by the relascope factor. The result is the estimated average basal area of the stand.

Note: In stands with a regular pattern of variation, e.g. line mixtures, the sample points should not be chosen at random, but chosen so that they give equal weighting to each component. For example, in 3 row hardwood/3 row conifer mixtures, all the sample points should be mid-way between a row of conifers and a row of broadleaves. In more complex line mixtures, or in line thinnings, it is advisable to place equal numbers of sample points between each pair of lines.

2. Using sampling plots.
   a. Choose a plot size which includes 7–20 measurable trees. Use rectangular plots where the planting rows are still clearly visible, and circular plots in all other stands. Tables 6 and 7 give the dimensions of a range of plots.

Table 6 Circular and square plot sizes

	Length in metres for plot size (ha)							
Shape	0.005	0.01	0.02	0.05	0.10	0.20	0.50	1.00
Circular (radius)	4.0	5.6	8.0	12.6	17.8	25.2	39.9	56.4
Square (sides)	7.1	10.0	14.1	22.4	31.6	44.7	70.7	100.0

Table 7 Rectangular plot sizes in plantations where rows are clearly visible

Average spacing between rows (m)	3 rows wide		4 rows wide	6 rows wide	9 rows wide
	Distance in metres along the row for plot size of				
	0.005 ha	0.01 ha	0.02 ha	0.05 ha	0.10 ha
1.5	11.1	22.2	33.3	55.6	74.1
1.6	10.4	20.8	31.2	52.1	69.4
1.7	9.8	19.6	29.4	49.0	65.4
1.8	9.3	18.5	27.8	46.3	61.7
1.9	8.8	17.5	26.3	43.9	58.5
2.0	8.3	16.7	25.0	41.7	55.6
2.1	7.9	15.9	23.8	39.7	52.9
2.2	7.6	15.2	22.7	37.9	50.5
2.3	7.2	14.5	21.7	36.2	48.3
2.4	6.9	13.9	20.8	34.7	46.3
2.5	6.7	13.3	20.0	33.3	44.4
2.6	6.4	12.8	19.2	32.1	42.7
2.7	6.2	12.3	18.5	30.9	41.2
2.8	6.0	11.9	17.9	29.8	39.7
2.9	5.7	11.5	17.2	28.7	38.3

Note:
Doubling the number of rows doubles the plot area, and similarly halving the distance halves the plot area.

b. Lay out plots throughout the stand. Table 8 gives a guide to the number needed. Plots should be laid out with care. The centre point of each circular plot must be chosen at *random*. The location of rectangular plots must also be chosen at random, but two of the sides of each plot must be parallel to the rows, and both must be midway between two adjacent rows. The boundary of each plot must be at least 5 m from the edge of the stand. The dimensions of the plots should be measured horizontally. If this is not possible on sloping ground, multiply the dimension given in Table 6 or 7 by the secant from Table 5. Use this corrected dimension for measuring directly up or down the slope.

Table 8 Number of sample plots

Area of stand (ha)	Uniform crop	Variable crop
0.5–2	6	8
2–10	8	12
Over 10	10	16

c. Measure the dbh of all the trees in the plot, and record the number of trees in each dbh class of 7 cm or more.
d. Using Table 2 (page 9) find the basal area appropriate to each dbh class, and multiply by the number of trees in each dbh class to give the total basal area in each class.
e. Add all these basal areas together and divide by the number of plots, to give an average basal area per plot.
f. Divide the average basal area per plot by the individual plot area to give the estimated average basal area per hectare of the stand.

Further information on basal area is given in the *Forest Mensuration Handbook*, Part IV, Procedure 9, pp. 81–82.

Further information on relascopes is given in the *Forest Mensuration Handbook*, Part V, Chapter 3, pp. 135–142.

Measuring weight

All weights should be measured in tonnes, and recorded to two or three significant figures as required.

The weight of a load of timber is usually measured by subtracting the weight of the empty lorry (tare weight) from the weight of the lorry when loaded (gross weight). The weight of fuel, oil, water, bolsters and chains, etc., must be the same at each weighing.

The weight of any stack of timber will decrease as the timber dries out, and the rate of drying depends on the weather and the way the timber is handled. In particular, if the bark is removed the timber will dry out much more rapidly. Coniferous timber which is unbarked (i.e. with the bark on) is likely to lose about two per cent of its weight each week during the summer and about half per cent weekly during the winter. Table 9 gives an estimate of the density of *fresh felled* timber in tonnes per cubic metre. The figures are only averages, and will vary with the time of year, the site, and the age of the tree.

The measurement of weight in order to estimate the volume of a load is described on pages 60–61.

Table 9 Density of fresh felled timber

Species	Tonnes/cu m	Species	Tonnes/cu m
SP	1.02	RC/LC	0.89
CP	1.00	GF	0.85
LP	0.95	NF	0.93
SS	0.92	Oak	1.06
NS	0.96	Beech	1.03
EL	0.90	Ash	0.78
JL/HL	0.83	Sycamore	0.83
DF	0.87	Birch	0.93
WH	0.93	Elm	1.03

Further information on weight is given in the *Forest Mensuration Handbook*, Part III, pp. 36–40.

Measuring volume

All volumes should be recorded in cubic metres to two or three significant figures as required.

The conventional top diameter limit for volume is 7 cm overbark, or the point at which no main stem is distinguishable, whichever comes first. So trees with a diameter at breast height of less than 7 cm are normally ignored when estimating volume.

There are three situations in which volume measurement can be required:

1. To estimate the volume of a standing tree.
   a. Use the following procedure, which is described in more detail in the *Forest Mensuration Handbook*, Part IV, Procedure 7, pp. 44–64.
      i. Measure the dbh of the tree.
      ii. Measure its total height if it is a conifer or its timber height if it is a broadleaved tree.
      iii. Use the appropriate single tree tariff chart in the *Forest Mensuration Handbook* to find the tariff number of the tree.
      iv. Find the volume from the tariff chart in the centre of this booklet or from the tariff tables in the *Forest Mensuration Handbook*.
   b. If the single tree tariff charts are not available or the tree is outside the range of the charts, use one of the procedures on the next two pages.

2. To estimate the volume of a stand.
   See pages 18–49.

3. To estimate the volume of felled timber.
   See pages 50–61.

Further information on volume is given in the *Forest Mensuration Handbook*, Part II, p. 19.

Alternative methods for estimating the volume of a standing tree

These methods should only be used if the single tree tariff charts are not available, or if the tree is outside the range of the charts.

1. For trees with a single main stem up to a diameter of 7 cm, and a timber height of not more than 12 m
   a. Measure the dbh in cm.
   b. Measure the timber height in m.
   c. Work out the basal area, using Table 2 on page 9.
   d. Calculate the volume by using the following formula, which is based on the end diameters method described on page 51:

$$V = (\frac{BA}{2} + 0.0019) \times H$$

   where V = volume in cubic metres
   BA = basal area in square metres
   H = timber height in metres.

2. For other trees
   a. Measure the dbh in cm.
   b. Measure the timber height in m.
   c. Estimate the diameter of the mid point of the timber length by using one of the following methods:
      i. use an optical caliper, e.g. a Wheeler pentaprism. This is the most accurate method.
      ii. use the following formula, which is based on a taper of 1 in 100:

$$D_m = dbh - \frac{H}{2}$$

      where D_m = diameter at mid point in cm
      dbh = diameter at breast height in cm
      H = timber height in m.
      This method is not suitable for open grown or heavily buttressed trees. Use method iii for these.

iii. Estimate the taper of the stem by measuring the diameter at 0.8 m (0.5 m below breast height) and at 1.8 m (0.5 m above breast height), and then use the following formula to estimate the mid diameter. This assumes that the taper from the base to the mid point of the tree is the same as the taper from 0.8 m to 1.8 m.

$$D_m = dbh - (D_1 - D_2) \times \frac{H}{2}$$

where D_m = diameter at mid point in cm
dbh = diameter at breast height in cm
D_1 = diameter at 0.8 m in cm
D_2 = diameter at 1.8 m in cm
H = timber height in m.

d. Estimate the volume by using the mid diameter method for felled trees, as described on page 52.

3. A rough estimate of the volume of a standing tree can be derived using the following method, based on form factors
   a. Measure the dbh of the tree.
   b. Calculate its basal area.
   c. Measure the total height of the tree.
   d. Estimate the form factor of the tree. 0.5 is appropriate for most mature conifers in plantations, and 0.4 for open grown conifers, while a lower form factor, down to 0.35, is more appropriate for younger trees.
   e. Multiply the total height by the basal area and by the form factor to give the estimated total volume.

Measuring the Volume of Standing Timber

The volume of standing timber is usually measured overbark, except for individual trees of high value. There are many ways of estimating the volume of standing timber, and the following key should be used

Question	Answer	Next Question	Methods	Page
1. Are the trees standing?	Yes	2		
(Not windblown or felled)	No	8		
2. Is the stand being measured for sale?	Yes	3		
(Not for inventory, or assessing piece-work rates)	No	7		
3. What is the value of the stand?*	Very high	4		
	High	5		
	Average	6		
	Low	7		
4. Very high value stands should be sold on the basis of measurement of the felled timber†			End diameters or mid diameter	51 52

*A stand may be of low value because the trees are small or of poor quality, or because the total volume is small, or because access is difficult, or for other similar reasons.

to choose the best method for any given situation. When timber is being offered for sale, the seller must make clear exactly which method has been used.

Question	Answer	Next Question	Methods	Page
5. High value stands should be sold on tariff measure.			Tariffing	25–27
6. Average value stands.	Yes		Tariffing	25–27
Are the trees being marked?	No	7		
7. Is it convenient to use a relascope, AND is an estimate of	Yes		Basal area and form height	20–24
total volume alone sufficient?	No		Abbreviated tariffing	28–45
8. Are only stumps remaining?	Yes		Volume estimation from stumps	46
	No		Volume estimation in windblown stands	47

†If, in place of this, an estimate of the volume is required before felling, either measure the volume of each tree (pp. 15–17) or tariff the stand (pp. 25–27).

Estimation of total volume via basal area and form height

This method should be used when an estimate of total volume alone is sufficient; when doing an inventory, or for stands of low value.

Field work:

a. Locate at least 'n' sample points at random throughout the stand, where n is read from Table 10. (For mixtures, see note on page 11.) Points close to the edge of the stand (see Table 11) should be replaced with new random points.
b. At each point, estimate the basal area with a relascope (as described on pages 10–11), and record the number of trees counted.
c. At every 2nd point measure and record the total height of the tree with the largest diameter within 5.6 m of the point.

Table 10 Number of relascope sweeps

Area of stand (ha)	Uniform crop	Variable crop
0.5–2	12	16
2–10	16	24
Over 10	20	32

Table 11 Minimum distances (in metres) of sample points from edge of stand

Maximum likely dbh of trees (cm)	Relascope factor	
	2	0.5
20	7	14
30	11	21
40	14	28
50	18	35
60	21	42
70	25	49
80	28	56

Office work:

a. Work out the mean basal area per ha by calculating the average number of trees counted at each point and multiplying by the relascope factor.
b. Derive the top height of the stand by calculating the average of all the heights measured.
c. Convert the top height to form height, using Table 12 (pages 22–24) (or use the Stand Volume Charts in the *Forest Mensuration Handbook* to replace both this step and step d).
d. Multiply the form height by the basal area per ha to give the estimated volume per ha.
e. Measure the stocked area of the stand. It is very important that the area is measured accurately; this is a frequent cause of error. If the area is being estimated from a large-scale map, the precise boundaries of the stand should be checked very carefully.
f. Multiply the estimated volume per hectare by the stocked area to give the estimated total volume.

Further information is given in the *Forest Mensuration Handbook*, Part IV, Procedure 9, pp. 81–107.

Table 12 Form height

Top Height (m)	Species						
	SP	CP	LP	SS	NS	EL	JL/HL
8.0	3.08	3.30	2.99	3.24	2.97	2.53	2.85
8.5	3.32	3.55	3.25	3.47	3.20	2.79	3.12
9.0	3.55	3.81	3.52	3.69	3.43	3.05	3.39
9.5	3.79	4.06	3.78	3.91	3.67	3.31	3.66
10.0	4.02	4.31	4.04	4.13	3.90	3.57	3.93
10.5	4.25	4.56	4.30	4.36	4.13	3.83	4.20
11.0	4.49	4.82	4.56	4.58	4.37	4.09	4.47
11.5	4.72	5.07	4.82	4.80	4.60	4.35	4.74
12.0	4.96	5.32	5.08	5.02	4.84	4.61	5.01
12.5	5.19	5.57	5.34	5.25	5.07	4.87	5.27
13.0	5.43	5.83	5.61	5.47	5.30	5.13	5.54
13.5	5.66	6.08	5.87	5.69	5.54	5.39	5.81
14.0	5.89	6.33	6.13	5.91	5.77	5.65	6.08
14.5	6.13	6.58	6.39	6.14	6.00	5.91	6.35
15.0	6.36	6.84	6.65	6.36	6.24	6.17	6.62
15.5	6.60	7.09	6.91	6.58	6.47	6.43	6.89
16.0	6.83	7.34	7.17	6.80	6.70	6.69	7.16
16.5	7.06	7.59	7.44	7.03	6.94	6.95	7.43
17.0	7.30	7.85	7.70	7.25	7.17	7.21	7.70
17.5	7.53	8.10	7.96	7.47	7.40	7.48	7.97
18.0	7.77	8.35	8.22	7.69	7.64	7.74	8.24
18.5	8.00	8.60	8.48	7.91	7.87	8.00	8.51
19.0	8.23	8.86	8.74	8.14	8.10	8.26	8.78
19.5	8.47	9.11	9.00	8.36	8.34	8.52	9.04
20.0	8.70	9.36	9.27	8.58	8.57	8.78	9.31
20.5	8.94	9.61	9.53	8.80	8.81	9.04	9.58
21.0	9.17	9.87	9.79	9.03	9.04	9.30	9.85
21.5	9.41	10.12	10.05	9.25	9.27	9.56	10.12
22.0	9.64	10.37	10.31	9.47	9.51	9.82	10.39
22.5	9.87	10.62	10.57	9.69	9.74	10.08	10.66
23.0	10.11	10.88	10.83	9.92	9.97	10.34	10.93
23.5	10.34	11.13	11.10	10.14	10.21	10.60	11.20
24.0	10.58	11.38	11.36	10.36	10.44	10.86	11.47
24.5	10.81	11.63	11.62	10.58	10.67	11.12	11.74
25.0	11.04	11.89	11.88	10.81	10.91	11.38	12.01
25.5	11.28	12.14	12.14	11.03	11.14	11.64	12.28
26.0	11.51	12.39	12.40	11.25	11.37	11.90	12.55
26.5	11.75	12.65	12.66	11.47	11.61	12.16	12.81
27.0	11.98	12.90	12.92	11.70	11.84	12.42	13.08
27.5	12.22	13.15	13.19	11.92	12.07	12.68	13.35
28.0	12.45	13.40	13.45	12.14	12.31	12.94	13.62
28.5	12.68	13.66	13.71	12.36	12.54	13.20	13.89
29.0	12.92	13.91	13.97	12.58	12.78	13.46	14.16
29.5	13.15	14.16	14.23	12.81	13.01	13.72	14.43
30.0	13.39	14.41	14.49	13.03	13.24	13.98	14.70

Table 12 Form Height (*continued*)

Top Height (m)	Species						
	DF	WH	RC	LC	GF	NF	OMS
8.0	2.90	3.64	2.95	2.44	2.93	3.37	3.06
8.5	3.12	3.86	3.14	2.83	3.17	3.60	3.35
9.0	3.33	4.09	3.34	3.21	3.41	3.83	3.65
9.5	3.54	4.31	3.53	3.59	3.64	4.05	3.95
10.0	3.76	4.53	3.72	3.97	3.88	4.28	4.24
10.5	3.97	4.75	3.92	4.34	4.12	4.51	4.54
11.0	4.18	4.97	4.11	4.71	4.35	4.74	4.84
11.5	4.40	5.19	4.31	5.07	4.59	4.97	5.13
12.0	4.61	5.42	4.50	5.43	4.83	5.20	5.43
12.5	4.82	5.64	4.70	5.78	5.06	5.43	5.73
13.0	5.04	5.86	4.89	6.13	5.30	5.66	6.02
13.5	5.25	6.08	5.08	6.48	5.54	5.89	6.32
14.0	5.46	6.30	5.28	6.82	5.77	6.12	6.61
14.5	5.68	6.52	5.47	7.15	6.01	6.35	6.91
15.0	5.89	6.75	5.67	7.48	6.25	6.58	7.21
15.5	6.10	6.97	5.86	7.80	6.48	6.80	7.50
16.0	6.32	7.19	6.06	8.13	6.72	7.03	7.80
16.5	6.53	7.41	6.25	8.44	6.96	7.26	8.10
17.0	6.74	7.63	6.45	8.75	7.19	7.49	8.39
17.5	6.96	7.85	6.64	9.06	7.43	7.72	8.69
18.0	7.17	8.07	6.83	9.36	7.67	7.95	8.99
18.5	7.38	8.30	7.03	9.66	7.90	8.18	9.28
19.0	7.60	8.52	7.22	9.95	8.14	8.41	9.58
19.5	7.81	8.74	7.42	10.24	8.38	8.64	9.87
20.0	8.02	8.96	7.61	10.52	8.61	8.87	10.17
20.5	8.24	9.18	7.81	10.80	8.85	9.10	10.47
21.0	8.45	9.40	8.00	11.07	9.09	9.32	10.76
21.5	8.66	9.63	8.19	11.34	9.32	9.55	11.06
22.0	8.88	9.85	8.39	11.61	9.56	9.78	11.36
22.5	9.09	10.07	8.58	11.86	9.80	10.01	11.65
23.0	9.30	10.29	8.78	12.12	10.03	10.24	11.95
23.5	9.52	10.51	8.97	12.37	10.27	10.47	12.25
24.0	9.73	10.73	9.17	12.62	10.51	10.70	12.54
24.5	9.94	10.95	9.36	12.86	10.74	10.93	12.84
25.0	10.16	11.18	9.55	13.09	10.98	11.16	13.13
25.5	10.37	11.40	9.75		11.22	11.39	
26.0	10.58	11.62	9.94		11.45	11.62	
26.5	10.80	11.84	10.14		11.69	11.85	
27.0	11.01	12.06	10.33		11.93	12.07	
27.5	11.22	12.28	10.53		12.16	12.30	
28.0	11.44	12.51	10.72		12.40	12.53	
28.5	11.65	12.73	10.92		12.64	12.76	
29.0	11.86	12.95	11.11		12.87	12.99	
29.5	12.08	13.17	11.30		13.11	13.22	
30.0	12.29	13.39	11.50		13.35	13.45	

Table 12 Form Height (*continued*)

Top Height (m)	Species OAK	BEECH	SAB	POP	
8.0	2.40	1.32	0.95	2.60	SAB–Use for
8.5	2.71	1.64	1.45	2.83	Sycamore, Ash,
9.0	3.02	1.95	1.91	3.06	Birch and Alder
9.5	3.32	2.27	2.35	3.28	
10.0	3.61	2.58	2.76	3.51	BEECH–Use
10.5	3.91	2.88	3.15	3.73	also for
11.0	4.19	3.19	3.52	3.94	Sweet
11.5	4.48	3.48	3.87	4.16	Chestnut
12.0	4.76	3.78	4.21	4.37	
12.5	5.04	4.07	4.53	4.58	
13.0	5.31	4.36	4.83	4.79	
13.5	5.58	4.65	5.13	4.99	
14.0	5.85	4.93	5.41	5.20	
14.5	6.11	5.21	5.68	5.40	
15.0	6.36	5.48	5.95	5.59	
15.5	6.62	5.75	6.20	5.79	
16.0	6.87	6.02	6.44	5.98	
16.5	7.11	6.29	6.68	6.17	
17.0	7.35	6.55	6.90	6.35	
17.5	7.59	6.81	7.12	6.54	
18.0	7.82	7.06	7.34	6.72	
18.5	8.05	7.31	7.55	6.90	
19.0	8.28	7.56	7.75	7.07	
19.5	8.50	7.80	7.94	7.25	
20.0	8.72	8.04	8.13	7.42	
20.5	8.93	8.28	8.32	7.58	
21.0	9.14	8.52	8.50	7.75	
21.5	9.35	8.75	8.67	7.91	
22.0	9.55	8.97	8.84	8.07	
22.5	9.75	9.20	9.01	8.23	
23.0	9.94	9.42	9.17	8.38	
23.5	10.13	9.63	9.33	8.53	
24.0	10.32	9.85	9.49	8.68	
24.5	10.50	10.06	9.64	8.83	
25.0	10.68	10.26	9.79	8.97	
25.5	10.85	10.46	9.93	9.12	
26.0	11.02	10.66	10.07	9.25	
26.5	11.19	10.86	10.21	9.39	
27.0	11.35	11.05	10.35	9.52	
27.5	11.51	11.24	10.48	9.65	
28.0	11.67	11.43	10.61	9.78	
28.5	11.82	11.61	10.74	9.91	
29.0	11.96	11.79	10.87	10.03	
29.5	12.11	11.96	10.99	10.15	
30.0	12.25	12.13	11.11	10.27	

Tariffing

This method should be used when measuring, for sale, stands of high value, and stands of average value when the trees are being marked.

Important
The following notes are only intended as an aide-memoire. It is essential that foresters engaged on tariffing are fully familiar with the whole tariffing procedure as described in the *Forest Mensuration Handbook*, Part IV, Procedure 8, pp. 65–80.

Pre-field work

a. Divide the stand into separate parts which are of acceptable uniformity. This broadly entails separating species, storeys, and areas of different heights or ages and measuring each of these strata independently.
b. Estimate the number of trees of at least 10 cm dbh. It is important that smaller trees are not included, as they are not used in the estimation of tariff number.
c. Discover if the dbh range is unusually wide by measuring the largest and smallest dbh in a random sample of 20 trees, and comparing with Table 13. This affects the choice of sampling scheme.

Table 13 Normal dbh ranges

Largest + smallest dbh	Normal dbh range	Largest + smallest dbh	Normal dbh range	Largest + smallest dbh	Normal dbh range
18	7	46	19	74	32
20	7	48	20	76	33
22	8	50	21	78	34
24	9	52	22	80	35
26	10	54	23	82	36
28	11	56	24	84	37
30	12	58	25	86	38
32	13	60	26	88	39
34	14	62	27	90	40
36	15	64	27	92	41
38	16	66	28	94	42
40	16	68	29	96	43
42	17	70	30	98	44
44	18	72	31	100	45

Note: Where 'largest + smallest' is an odd number, take next higher even number.

d. Choose the appropriate sampling scheme from the key (Figure 1).
e. Choose the appropriate sampling fraction from Table 14.

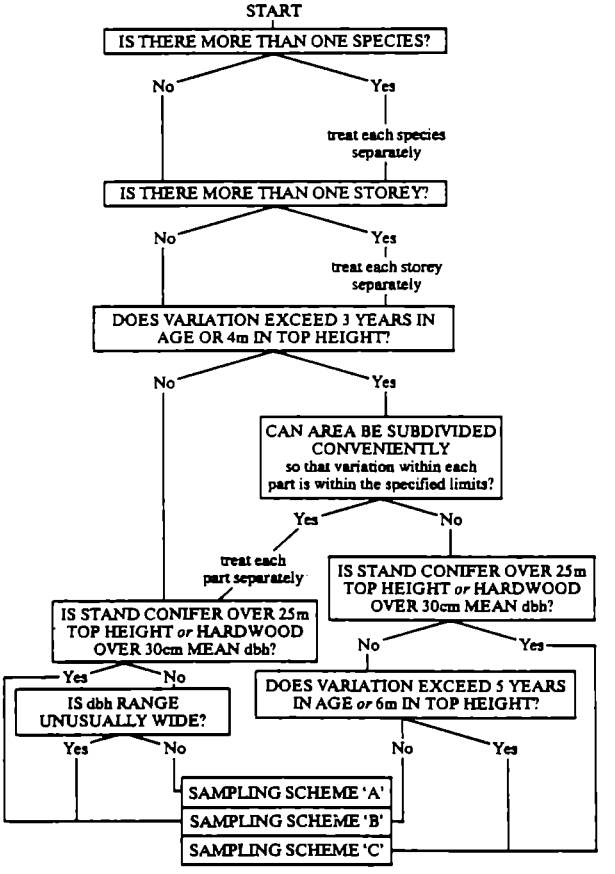


Figure 1 Key to sampling schemes

Field work

a. Measure and record the dbh of every 'n'th tree, counting only those trees with a dbh of 7 cm or more, where n is the sampling fraction.
b. Fell every 10th girthed tree, if it has a dbh of at least 10 cm. (The figures in brackets in Table 14 are the exceptions to this. For example, if sampling scheme 'A' has been chosen and there are 180 trees, then girth all trees but only fell every 15th tree, if it has a dbh of at least 10 cm.)

c. Measure the timber length, record the rounded down length, and measure and record the mid diameter. Trees with a timber length of more than 20 m must be measured in two sections.

Table 14 Sampling fractions

Estimated nos. of trees (of 10 cm dbh and above)	Girth sampling fraction A	B	C
100–150	1:1	1:1	1:1
151–200	1:1 (15)	1:1	1:1
201–300	1:1 (15)	1:1	1:1
301–400	1:1 (20)	1:1 (12)	1:1
401–500	1:2	1:1 (15)	1:1
501–600	1:2	1:1 (15)	1:1 (12)
601–800	1:3	1:2	1:1 (15)
801–1 000	1:4	1:3	1:2
1 001–1 200	1:5	1:3	1:2
1 201–1 400	1:6	1:4	1:3
1 401–1 600	1:7	1:4	1:3
1 601–1 800	1:8	1:5	1:4
1 801–2 000	1:9	1:6	1:4
2 001–2 400	1:10	1:6	1:5
2 401–3 000	1:12	1:8	1:6
3 001–4 500	1:15	1:10	1:7
4 501–6 000	1:20	1:15	1:10
6 001–8 000	1:25	1:18	1:12
8 001–10 000	1:30	1:20	1:15
10 001+	1:40	1:25	1:20

Office work

a. Calculate the volume of each felled tree, using mid diameter volume tables.
b. Calculate the tariff number of each felled tree, using the tariff tables in the *Forest Mensuration Handbook*. If the volume is exactly midway between two tariff numbers, use the lower tariff number.
c. Calculate the average tariff number and round it down to the nearest whole number.
d. Count the number of measured trees in each diameter class and multiply this by the sampling fraction.
e. Using the rounded down tariff number, and the tariff tables, calculate the volume for each diameter class.
f. Multiply the number of trees in each class by its volume, to give the total volume for that class.
g. Add up all the class volumes to give the overall total volume.
h. Carry out the checks described in the *Forest Mensuration Handbook* on page 75.

Abbreviated tariffing

This method should only be used

a. for low value stands, and for those of average value which are not being marked, to provide a buyer with guidance on the volume and numbers of trees—for example, when standing sales are being offered on a weight out-turn or area basis, and
b. for any stands for which a volume estimate is required but the stand is not being offered for sale.

Before any method of abbreviated tariffing is used, a full understanding of the tariff system is essential. These notes cover the main points, but further information is given in the *Forest Mensuration Handbook*, Part IV, Procedure 8, pp. 65–80.

There are basically two steps required for estimating the volume of a stand using the tariff system.

Step I

Estimate the total number of trees (either by counting them, or by estimating their average stocking) and the proportion in each dbh class (either by measuring all the trees or by measuring a sample).

Step II

Choose a suitable Tariff Number (either from experience of similar stands, or by taking measurements in the stand) or choose a suitable Local Volume Table. (Local Volume Tables give a volume for each dbh class. Tariff Tables consist of a series of Local Volume Tables; the Tariff Number specifies a particular table in the series.)

The results of these two steps are combined to give an estimate of the mean volume of the trees in the stand and of the total volume of the stand, as described on pages 44–45.

There are several ways of carrying out each step, and these are given on page 30 (Step I—Methods A, B and C) and pages 31, 34 and 35 (Step II—Methods 1 to 7).

Any method for Step I can be combined with any method for Step II, and the descriptions enable the forester to choose which pair of methods is best for his situation. Suggested combinations for particular situations are given below. If two alternative methods are equally suitable, the more accurate one should be chosen.

The percentage given in brackets after most of the methods is a *rough* guide to the expected accuracy. In most cases the true answer can be expected to be within the range of the estimated answer plus or minus the percentage given. The percentage only applies to each separate step, and it is necessary to combine the percentages to derive the accuracy of the complete volume estimate. This is done by squaring the percentage for each step, adding the two results together, and taking the square root. For example, Method A for Step I combined with Method 3 for Step II has an accuracy of just over 11 per cent ($\sqrt{8^2 + 8^2}$), while Method A for Step I combined with Method 6 for Step II has an accuracy of just under 13 per cent ($\sqrt{8^2 + 10^2}$).

No estimate is given for the accuracy of Methods 1 and 2 for Step II as these are extremely variable. An accurately known tariff number or a good Local Volume Table will be as accurate as any of the other methods, but a poor one will be much worse.

The various combinations of methods are described on pages 38–43.

Suggested combinations:

First thinning of Sitka Spruce plantation	C6
Clearfelling of unthinned Sitka spruce plantation	C3
Selective thinning of low value crop	A4
Clearfelling of low value, pure, even-aged conifer	C6
Clearfelling of low value, mixed, broadleaf	B5

Step I

Methods for estimating the total number of trees and the proportion in each dbh class

Method A (8%)–Count all the trees and measure a sample of them . . . page 38.

This method can only be used if the trees are being marked, and an estimate of volume is not required until the whole stand has been marked.

Method B (10%)–Lay out and measure sample plots . . . page 40.

This method can be used in any situation, but it is often unreasonably expensive.

Method C (10%–12%)–Measure small groups of trees and estimate their average spacing . . . page 42.

This method is quicker than the previous two, and should always be used if an estimate of the mean volume per tree is required, but not the total volume. If the total volume is required as well, this method should only be used in pure stands which are evenly stocked, when the accuracy is likely to be as good as Method B.

Step II

Methods for choosing the tariff number or the local volume table

Method 1–use an existing local volume table

Method 2–use a representative tariff number

If the stand to be measured is known to be very similar to stands which have been measured previously, then the same tariff number can be used without any further measurement. This method should be used with care, as the tariff number of a stand changes with age. A previously constructed local volume table is more reliable, but this will be affected by any changes in management techniques. One local volume table is unlikely to apply to stands of different ages or on different sites. A local volume table can be constructed from past records of similar stands which have been tariffed, but all local volume tables should be checked regularly.

Continued on page 34.

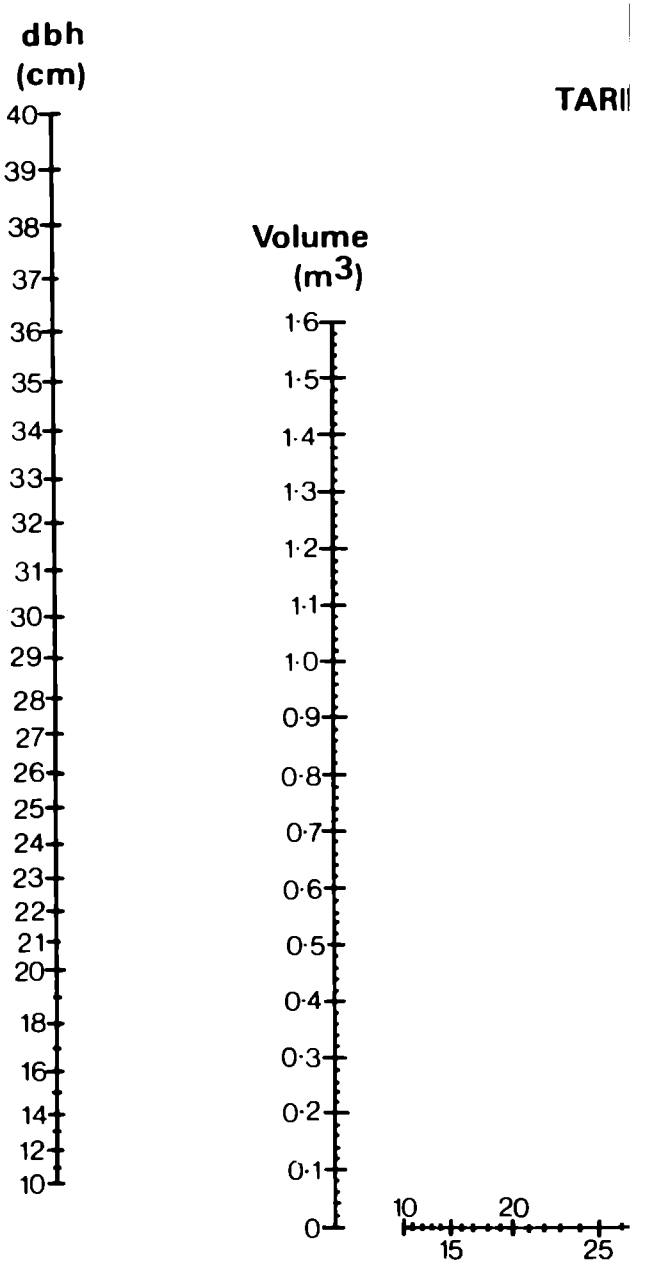
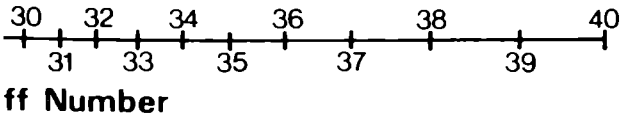


Figure 2 Tariff number chart

UMBER CHART



Step II (*continued*)

Methods 3–7

It will usually be necessary to take measurements in the stand to determine the appropriate tariff number. The first of the following five methods is the most accurate, but as well as being the most expensive, it can only be used if trained tree fellers are available. The other four methods all involve measuring the heights of trees, and the choice of method depends on how difficult height measurement is in the stand. It is important to remember that accurate use of hypsometers requires training, checking, and, most of all, practice.

Method 3 (8%)–fell sample trees

a. Fell each sample tree with a dbh of 10 cm or more, and measure its length and mid diameter.
b. Work out its volume using the mid diameter method (page 52), and then its tariff number by referring to the tariff tables in the *Forest Mensuration Handbook*. As an alternative, the tariff number may be derived from the alignment chart, Figure 2, in the middle of this booklet, or from the following formula:

$$T = 0.139 + \frac{202 \times (200 \times V - 1)}{(dbh^2 - 49)}$$

where T = tariff number
V = volume in cu m
and dbh = dbh in cm

c. After calculating the tariff number of each sample tree, work out the average tariff number.

Method 4 (9%)–conifers only. Measure total height of sample trees

a. Measure the total height of each sample tree with a dbh of 10 cm or more.
b. Estimate its tariff number from its dbh and total height by using the appropriate Single Tree Tariff Chart (*Forest Mensuration Handbook*, Charts 1–12, pp. 46–57).
c. After estimating the tariff number of each sample tree, work out the average tariff number.

Method 5 (9%)–broadleaves only. Measure timber height of sample trees

a. Measure the timber height of each sample tree with a dbh of 10 cm or more.
b. Estimate its tariff number from its dbh and timber height by using the appropriate Single Tree Tariff Chart (*Forest Mensuration Handbook*, Charts 13–19, pp. 58–64).
c. After estimating the tariff number of each sample tree, work out the average tariff number.

Method 6 (10%)–estimate top height of stand

a. Measure the total height of a sample of 'top height trees'.
b. Work out the average of these heights. This is the estimated top height of the stand.
c. Convert this to an estimated tariff number by using the top height/tariff number table (Table 15, pp. 36–37).

Method 7 (11% or more)–measure height of sample trees

a. Measure the total height, or timber height, of sample trees with a dbh of 10 cm or more.
b. Estimate the volume of each sample tree using one of the methods on pages 16–17 and then convert this to tariff number as described under Method 3 opposite.
c. After estimating the tariff number of each sample tree, work out the average tariff number.

CAUTION. Method 7 should only be used in one of the following circumstances:

i. A rough answer is required quickly, and the *Forest Mensuration Handbook* is not available.
ii. The species is not covered by the tables or charts in the *Forest Mensuration Handbook*.
iii. The trees are bigger or smaller than the limits of the tables or charts in the *Forest Mensuration Handbook* (in which case Method 3 is probably more appropriate).
iv. The trees are of unusual form, e.g. open grown, heavily branched, or with severe buttressing.

Table 15 Tariff numbers

Top Height (m)	Species SP	CP	LP	SS	NS	EL	JL/HL	
8.0	17	16	15	16	16	14	16	Subtract 1
8.5	17	16	16	16	17	15	16	from the
9.0	18	17	16	17	18	15	17	tariff
9.5	18	18	17	18	18	16	18	number
10.0	19	18	18	18	19	17	18	for inter-
10.5	19	19	19	19	19	18	19	mediate
11.0	20	20	19	19	20	18	20	and low
11.5	20	20	20	20	20	19	20	selective
12.0	21	21	21	21	21	20	21	thinning
12.5	21	22	21	21	22	20	22	
13.0	22	23	22	22	22	21	22	
13.5	22	23	23	23	23	22	23	
14.0	23	24	24	23	23	22	24	
14.5	24	25	24	24	24	23	24	
15.0	24	25	25	24	24	24	25	
15.5	25	26	26	25	25	25	26	
16.0	25	27	26	26	26	25	26	
16.5	26	27	27	26	26	26	27	
17.0	26	28	28	27	27	27	28	
17.5	27	29	28	27	27	27	29	
18.0	27	30	29	28	28	28	29	
18.5	28	30	30	29	29	29	30	
19.0	28	31	31	29	29	29	31	
19.5	29	32	31	30	30	30	31	
20.0	29	32	32	30	30	31	32	
20.5	30	33	33	31	31	31	33	
21.0	30	34	33	32	31	32	33	
21.5	31	34	34	32	32	33	34	
22.0	31	35	35	33	33	34	35	
22.5	32	36	36	33	33	34	35	
23.0	32	37	36	34	34	35	36	
23.5	33	37	37	35	34	36	37	
24.0	33	38	38	35	35	36	37	
24.5	34	39	38	36	35	37	38	
25.0	34	39	39	36	36	38	39	
25.5	35	40	40	37	37	38	39	
26.0	35	41	40	38	37	39	40	
26.5	36	41	41	38	38	40	41	
27.0	36	42	42	39	38	40	42	
27.5	37	43	43	39	39	41	42	
28.0	37	43	43	40	40	42	43	
28.5	38	44	44	41	40	43	44	
29.0	38	45	45	41	41	43	44	
29.5	39	46	45	42	41	44	45	
30.0	39	46	46	42	42	45	46	

Table 15 Tariff numbers (*continued*)

Top Height (m)	Species							
	DF	WH	RC	GF	NF	OAK	BIRCH	
8.0	15	17	14	14	14	16	14	OAK
8.5	16	17	14	15	15	17	14	Use also for
9.0	16	18	15	16	16	17	15	Beech,
9.5	17	19	15	16	16	18	15	Ash, Elm,
10.0	17	19	16	17	17	18	16	Alder and
10.5	18	20	16	18	18	19	16	Sweet
11.0	18	20	17	18	18	19	17	Chestnut
11.5	19	21	17	19	19	20	17	
12.0	20	22	18	20	20	20	17	BIRCH
12.5	20	22	18	20	21	21	18	Use also for
13.0	21	23	19	21	21	21	18	Sycamore
13.5	21	24	19	22	22	22	19	and Poplar
14.0	22	24	20	23	23	22	19	
14.5	22	25	21	23	23	23	20	
15.0	23	25	21	24	24	23	20	
15.5	24	26	22	25	25	24	21	
16.0	24	27	22	25	25	24	21	
16.5	25	27	23	26	26	25	22	
17.0	25	28	23	27	27	25	22	
17.5	26	28	24	27	27	25	22	
18.0	26	29	24	28	28	26	23	
18.5	27	30	25	29	29	26	23	
19.0	28	30	25	29	29	27	24	
19.5	28	31	26	30	30	27	24	
20.0	29	31	26	31	31	28	25	
20.5	29	32	27	31	31	28	25	
21.0	30	33	27	32	32	28	25	
21.5	30	33	28	33	33	29	26	
22.0	31	34	29	34	33	29	26	
22.5	31	35	29	34	34	30	27	
23.0	32	35	30	35	35	30	27	
23.5	33	36	30	36	35	30	27	
24.0	33	36	31	36	36	31	28	
24.5	34	37	31	37	37	31	28	
25.0	34	38	32	38	37	31	28	
25.5	35	38	32	38	38	32	29	
26.0	35	39	33	39	39	32	29	
26.5	36	39	33	40	39	32	29	
27.0	37	40	34	40	40	33	30	
27.5	37	41	34	41	41	33	30	
28.0	38	41	35	42	41	34	30	
28.5	38	42	36	42	42	34	31	
29.0	39	43	36	43	43	34	31	
29.5	39	43	37	44	43	35	31	
30.0	40	44	37	44	44	35	32	

Combinations of Step I Method A with various methods for Step II

Pre-field work
Estimate the total number of trees with a dbh of 10 cm or more, and choose the appropriate sampling fraction from Table 16.

Table 16 Sampling fractions

No. of trees	Sampling fraction
Up to 100	1:1
101–200	1:2
201–300	1:3
301–400	1:4
401–600	1:5
601–800	1:6
801–1 000	1:8
1 001–1 300	1:10
1 301–1 600	1:12
1 601–2 200	1:15
2 201–3 000	1:20
3 001–4 000	1:25
Over 4 000	1:30

Step I–Field work
a. Count the trees as they are being marked.
b. Measure and record the dbh of every 'n'th tree where n is the sampling fraction.

Step II–Field work

The measurements required for choosing the tariff number or local volume table are different for the different methods of Step II, and are given below.

METHODS 1 AND 2

No further measurements are needed.

METHODS 3, 4, 5 AND 7

Every 10th measured tree is a sample tree and it is sampled if it has a dbh of 10 cm or more.

For methods 3, fell it, measure and record its dbh, timber length, and mid diameter.

For method 4, measure and record its dbh and total height.

For method 5, measure and record its dbh and timber height.

For method 7, measure and record its dbh and total height or timber height as required.

Note: there must be at least 10 sample trees.

METHOD 6

Measure and record the total height of the tree of largest diameter within 5.6 m of every 10th measured tree.

Office work

a. Choose the appropriate tariff number or local volume table as described on pages 31, 34, 35.
b. Calculate the mean volume of the trees as described on pages 44–45.
c. Multiply the mean volume by the total number of trees to give the estimated total volume of the stand.

Combinations of Step I Method B with various methods for Step II

Pre-field work–Any stand

a. Choose a convenient sample plot size which contains a minimum of 7, and preferably not more than 20, trees. There are tables of plot sizes on page 12.
b. Measure the stocked area of the stand. It is very important that the area is measured accurately; this is a frequent cause of error. If the area is being estimated from a large-scale map, the precise boundaries of the stand should be checked very carefully.

Pre-field work–Alternative for line thinnings only

a. Choose a convenient length of line to give a single line plot which contains a minimum of 7, and preferably not more than 20, trees.
b. Measure the total length of the lines which are to be thinned. It is very important that this is measured accurately.

Step I–Field work

a. Locate 'n' sample plots at random throughout the stand, where n is read from Table 17. All the plots must be the same size and shape, and the boundary of each plot should be at least 5 m from the edge of the stand.
b. Measure and record the dbh of all the trees in each plot.

Table 17 Number of sample plots

Area of stand (ha)	Uniform crop	Variable crop
0.5–2	6	8
2–10	8	12
Over 10	10	16

Step II–Field work

The measurements required for choosing the tariff number or local volume table are different for the different methods of Step II, and are given below.

METHODS 1 AND 2

No further measurements are needed.

METHODS 3, 4, 5 AND 7

In each plot, choose two trees, with a dbh of 10 cm or more, at random, and treat these as sample trees. This will give a total of at least 12 sample trees.

For method 3, fell each sample tree, measure and record its dbh, timber length, and mid diameter.

For method 4, measure and record the dbh and total height of each sample tree.

For method 5, measure and record the dbh and timber height of each sample tree.

For method 7, measure and record the dbh and total height or timber height of each sample tree, as required.

METHOD 6

Choose a random point in each plot, and measure and record the total height of the tree of largest diameter within 5.6 m of this point.

Office work

a. i. If the line thinning alternative has been used, work out the average number of trees per sample line, divide this by the length of each sample line, and multiply the result by the total length of the lines to be thinned, to give the total number of trees to be thinned.
   ii. Otherwise, work out the average number of trees per plot, divide this by the area of each plot, and multiply the result by the total area of the stand to give the total number of trees.
b. Choose the appropriate tariff number or local volume table as described on pages 31, 34, 35.
c. Calculate the mean volume of the trees as described on pages 44–45.
d. Multiply the mean volume by the total number of trees to give the estimated total volume of the stand, or of the trees to be thinned.

Combinations of Step I Method C with various methods for Step II

Pre-field work–Any stand
Measure the stocked area of the stand. It is very important that the area is measured accurately; this is a frequent cause of error. If the area is being estimated from a large-scale map, the precise boundaries of the stand should be checked very carefully.

Pre-field work–Alternative for line thinnings only
Measure the total length of the lines which are to be thinned. It is very important that this is measured accurately.

Step I–Field work
a. Locate 'n' sample trees at random throughout the stand, where n is read from Table 18. Trees within 10 m of the edge of the stand should be replaced with new random trees.
b. Measure and record the dbh of this tree and the 5 trees nearest to it. (When using the line thinning alternative, the 6 trees must be in one line.)
c. Measure and record the horizontal distance from the sample tree to the third nearest tree. (When using the line thinning alternative, measure and record the horizontal distance from the first tree to the sixth tree in the line.)

Table 18 Number of sample trees

Area of stand (ha)	Uniform crop	Variable crop
0.5–2	12	16
2–10	16	24
Over 10	20	32

Step II–Field work
The measurements required for choosing the tariff number or local volume table are different for the different methods of Step II, and are given below.

METHODS 1 AND 2
No further measurements are needed.

METHODS 3, 4, 5 AND 7
Take the third nearest tree as a volume sample tree. (For the line thinning alternative, take the sixth tree in the line.) If its dbh is less than 10 cm, take the next

nearest tree, and continue until one is found with a dbh of 10 cm or more.

For method 3, fell each volume sample tree, measure and record its dbh, timber length, and mid diameter.

For method 4, measure and record the dbh and total height of each volume sample tree.

For method 5, measure and record the dbh and timber height of each volume sample tree.

For method 7, measure and record the dbh and total height or timber height of each volume sample tree, as required.

METHOD 6

Measure and record the total height of the tree of largest diameter within 5.6 m of every second sample tree (as selected in Step I).

Office work

a. i. If the line thinning alternative has been used, work out the average distance between the first and sixth trees in the sample lines. Divide this by five to give the average spacing between trees. Work out the total number of trees to be thinned by dividing the total length of the lines to be thinned by the average spacing between trees.

ii. Otherwise, use the following formula (based on Kendall and Moran[1]) to estimate the total number of trees:

$$N = \frac{A \times 30\,000}{\pi \times R}$$

where N = total number of trees
A = total stocked area in hectares
R = mean squared distance to the third nearest tree in metres

R is calculated by squaring each measured distance, adding all the results together, and dividing by the number of measurements.

b. Choose the appropriate tariff number or local volume table as described on pages 31, 34, 35.

c. Calculate the mean volume of the trees as described on pages 44–45.

d. Multiply the mean volume by the total number of trees to give the estimated total volume of the stand, or of the trees to be thinned.

[1]Kendall, M. G. and Moran, P. A. P. (1963). *Geometrical Probability*, pp. 37–41, Griffin.

Calculations of the mean volume of the trees, and the total volume of the stand

There are two methods for working out the mean volume of the trees, and these are described opposite. The second method is easier. In both methods, the tariff number or the local volume table is used to convert a dbh to a volume, and if a tariff number is being used, this can be done in one of three ways.

a. Use the tariff tables in the *Forest Mensuration Handbook*, pp. 261–271.
b. Use the alignment chart (Figure 2) in the centre of this booklet.
c. Use the following formula:

$$\text{Volume in cu m} = \frac{52 - (12 \times T) - (0.0343 \times dbh^2) + (0.247 \times T \times dbh^2)}{10\,000}$$

where T = tariff number
and dbh = dbh in cm

Mean Volume–First Method
(This is the method used in the normal tariffing procedure)

a. Count the number of measured trees in each dbh class.
b. Using the tariff number or local volume table, calculate the volume for each dbh class.
c. Multiply the number of trees in each class by its volume, to give the total volume for that class.
d. Add up all the class volumes to give the total volume.
e. Divide by the total number of measured trees to give the mean volume.
f. The mean dbh can be derived from the mean volume by using the tariff table or local volume table (but see note below).

Mean Volume–Second Method

a. Count the number of measured trees in each dbh class.
b. Multiply the number of trees in each class by the square of the dbh, e.g. 8 trees with dbh of 11 cm gives $8 \times 11^2 = 968$.
c. Add up all the class totals, and divide by the total number of measured trees to give the mean squared dbh.
d. Work out the square root, to give the mean dbh.
e. Using the tariff number or local volume table, convert this mean dbh to the mean volume.

Note: This second method (and f above) do not work with local volume tables in which volume is not linearly related to basal area.

Total Volume
The mean volume is multiplied by the total number of trees in the stand to give the total volume in the stand.

Estimation of volume from stumps

If the trees have already been removed from the site it is impossible to make an accurate estimate of their volume, and only in very rare circumstances should such an estimate be required. If it is essential to make an estimate, the best approach is to find a similar area of woodland and to estimate the volume per hectare in this, using one of the methods described earlier in this booklet. If a similar stand cannot be found, then the following four-step method should be used.

a. Estimate the number of trees removed by counting the stumps of recently felled trees. This should be done by laying out sample plots, as described on pages 12–13. It is a great deal more difficult than counting trees.

b. Estimate the mean diameter of the trees removed. This is best done by estimating the mean diameter of a stand of trees of similar size. If this is not possible, then measure the underbark diameter of all the stumps which are counted, and convert each stump diameter to an estimated dbh by using the following formula[1]:

$$\text{dbh} = 1.6 + (0.7 \times \text{SD})$$

where dbh = overbark dbh in cm
SD = underbark stump diameter in cm

Then work out the mean diameter, as described on pages 8–9.

c. Estimate the average tariff number of the trees removed. This should be done by first estimating the top height of the stand–either by estimating the top height of an adjacent stand, or by estimating the total height of any remaining trees, or by guessing–and then using the Top Height/Tariff Number table (Table 15) on pages 36–37 to estimate the tariff number.

d. Finally, use the tariff tables in the *Forest Mensuration Handbook*, or the tariff chart in the centre of this booklet, to work out the mean volume associated with this mean diameter and tariff number, and multiply that by the number of stumps.

[1]Witts, M. D. and Christie, J. M. (1979). *Relationship of stump diameter to breast height girth*, Forestry Commission Internal Paper (unpublished).

Estimation of volume in windblown stands

There are no easy answers to the problem of estimating the volume of timber in an area of woodland that has been damaged by wind. Indeed, it is nearly always better to measure the timber after it has been removed from the site.

If it is essential to make an estimate of the volume of a windblown stand before it is cleared then the best approach is to find a similar area of woodland and to estimate the volume per hectare in this, using one of the methods described earlier in this booklet. This figure is then multiplied by the area of blown woodland to give an estimate of the volume blown. Alternatively, the volume per hectare of the blown woodland can be estimated from the appropriate yield model from *Yield Models for Forest Management*, Forestry Commission Booklet 48.

If a similar stand cannot be found, then method B6 described on pages 40–41 should be used. This involves setting up plots, counting the number of trees in each plot and measuring their dbh, and also estimating the top height of the stand. All these measurements can still be taken in a windblown stand, although sometimes with great difficulty. As an alternative, a 4 metre wide transect across the area could be used instead of the plots.

The following points should be remembered:

a. The plots must be located at *random*. There will be a temptation to site the plots in areas which have easy access, but these may not be typical. It is better not to attempt to estimate the volume if it cannot be done accurately.
b. In each plot, the trees to be counted and measured are those which would have been in the plot when the trees were standing. Some stems which were growing in the plot may have been blown out of it, and vice versa.
c. Top height will probably have to be estimated by measuring the total *length* of the trees of largest diameter–not the total height. In areas where windsnap is common, it may be easier to estimate the top height by measuring adjacent stands.

Further information can be obtained from the Mensuration Officer at Alice Holt.

Estimation of volume increment

It is occasionally necessary to estimate the present volume of a stand when it has already been measured a year or so before. In these circumstances it is best to measure the stand again, particularly for stands of high yield class or in those cases where the previous measurement was more than 2 years ago. Where this is thought to be unreasonably expensive the following procedure can be used to estimate the increment in volume since the last measurement, without taking any further measurements.

a. Select the yield model of the correct species and yield class from Forestry Commission Booklet 48 *Yield Models for Forest Management* which most closely parallels the past history of the stand. For example, choose an unthinned model for a stand which has not been thinned before, even if it is intended to thin it regularly in the future. Where several stands with different treatments have been combined, use an 'average' model.
b. Subtract the cumulative volume production at the age of the stand at the time of measurement, or the next earlier age if the actual age is not shown in the model, from the cumulative volume production at the next age shown in the model.
c. Divide this by the difference between the two ages shown in the model, to give the average annual volume increment over the period. This figure is used to adjust the estimated standing volume.
d. Use Table 19 to estimate the proportion of the annual volume increment to be added. For example, if the original estimate was made at the end of July, and a revised estimate of the volume is required at the end of the following May, then 0.6 times the annual increment calculated in paragraph c should be added (0.2 + 0.1 + 0.1 + 0.2).

Table 19 Proportion of annual volume increment in each month

January to April	0
May	0.2
June	0.2
July	0.2
August	0.2
September	0.1
October	0.1
November and December	0

e. i. For clear fellings, add the whole of the increment worked out in paragraph d.

ii. For line thinnings, add the appropriate proportion of the increment worked out in paragraph d. For example, for a 1 in 4 line thinning, add one quarter of the increment.

iii. For intermediate or crown thinnings, first work out the approximate proportion of the total volume of the stand which is being removed. Multiply the increment worked out in paragraph d by this proportion. Add the result to the estimated volume.

iv. For low selective thinnings, use the procedure in paragraph e iii, but in addition, multiply the result by 0.7 before adding it to the estimated volume.

Further information can be obtained from the Mensuration Officer at Alice Holt.

Measuring the Volume of Felled Timber

Overbark and underbark measurement

The volume of felled timber can be measured either overbark, i.e. including the bark, or underbark, i.e. excluding the bark. When timber is being offered for sale, and the details include an estimated volume, the description must state clearly whether the volume is overbark or underbark.

Barked timber (i.e. timber without bark or with the bark off) has to be measured underbark, and the volumes are always quoted underbark.

Unbarked timber (i.e. timber with the bark on) can be measured overbark by any of the methods described in this booklet. If the top diameter method of measurement (page 54) or the end diameters method (page 51) is being used, the timber can be measured either overbark or underbark. The choice depends on the use of the results. The volumes are usually quoted overbark if the timber was measured overbark, and underbark if it was measured underbark.

It is possible to convert overbark volumes to underbark volumes and vice versa, but this is rarely necessary except when measuring long sawlogs. These are normally measured mid diameter overbark, but the volumes are usually quoted underbark. The overbark volumes should be converted to underbark volumes by multiplying them by the factor given in Table 20 which is suitable for average British sawlogs between 8 m and 16 m long.

Table 20 Overbark to underbark volume conversion factors for long sawlogs

Species	Factor	Species	Factor
Scots pine Lodgepole pine Corsican pine Sitka spruce Norway spruce Grand fir Noble fir	0.87 0.83 0.92	European larch Japanese larch Hybrid larch Douglas fir Western hemlock Red cedar Lawson cypress	0.82 0.85 0.88 0.90

Further information on overbark and underbark measurements is given in the *Forest Mensuration Handbook*, Part V, Chapter 5, pp. 147–161.

End diameters method

This is usually more accurate than the mid diameter method (page 52), but it is rarely used because the increased accuracy is not worth the extra cost of the measurement. It is useful when either the mid point of a log is inaccessible, e.g. because it is in a stack of timber, or when an accurate underbark volume is required for a log with the bark on. It is not recommended for logs over 15 m long.

The measurements required are:

a. The length of each log in metres.
b. The diameters of both ends of each log in centimetres. These can be measured overbark (for an overbark volume) or underbark (for an underbark volume).

The volume is worked out by first finding the diameter relating to the mean cross-sectional area of the ends. This can be done by one of two methods:

i. Use Table 2 on page 9 to find the cross-sectional area of each end; work out the mean of the two areas; and use Table 2 again to derive the appropriate diameter.
ii. Square each diameter; work out the mean of these two results and calculate the square root.

This diameter is then used as the mid diameter for entering the mid diameter volume tables (Booklet 26 or 39), or the alignment chart in Figure 3. This procedure is based on Smalian's formula:

$$\text{Volume in cu m} = \frac{\pi \times L}{40\,000} \times \frac{d^2 + D^2}{2}$$

where L = length in m
d = small end diameter in cm
D = large end diameter in cm

Mid diameter method

This is the traditional method for estimating the volume of logs. Although it is a very accurate method, it becomes less accurate as the length increases.

The measurements required are:

a. The length of each log in metres. If this is more than 15 m, it is better to measure the log in two sections. This *must* be done if the length is greater than 20 m.
b. The diameter of the mid point of each log in cm. The mid point must be found by measuring half the rounded down length from the *butt end* of the log.

The volume is calculated by using the mid diameter volume tables given in Forestry Commission Booklets 26 and 39, which are based on Huber's formula:

$$\text{Volume in cu m} = \frac{\pi \times d^2 \times L}{40\,000}$$

where d = mid diameter in cm
L = length in m

An approximate volume can be read from Figure 3. When using the volume tables with logs over 10 m long, it is possible to add lengths together. For example, if a 13.8 m log has a mid diameter (at 6.9 m) of 15 cm, its volume is exactly double the volume of a 6.9 m log of mid diameter 15 cm.

Further information on the mid diameter method of measurement is given in the *Forest Mensuration Handbook*, Part III, Procedure 1, pp. 20–21.

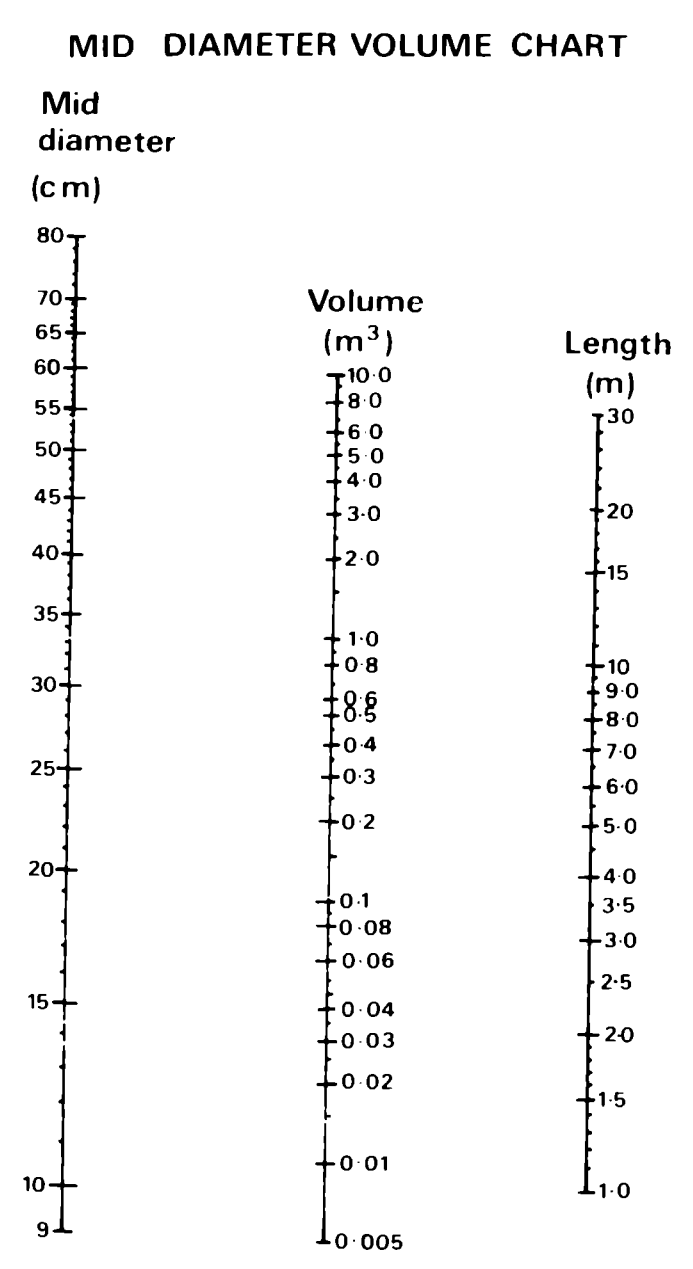


Figure 3 Mid diameter volume chart

Top diameter method

Because of the need to assume a conventional rate of taper, volume estimates derived by this method are subject to greater errors than by the previous two methods. The conventional rates of taper may not necessarily represent the average rates found in different areas. However, the results from top diameter measurement are often more meaningful to a potential buyer, and it is a quicker method to use.

Three rates of taper are in common use in Britain. These are:

a. 1 in 120 for sawlogs and other timber from the lower part of the stem.
b. 1 in 100 for long poles.
c. 1 in 84 for pitwood and other timber from the upper part of the stem.

The measurements required are:

i. The length of each log in metres.
ii. The diameter of the small end of each log in centimetres. This can be measured overbark (for an overbark volume) or underbark (for an underbark volume). The smallest diameter should be used if the top end of the log is not circular.

The volume is calculated by using the Top Diameter tables published by the Forestry Commission in Booklets 31, 37 and 39 which are based on the following formula:

$$\text{Volume in cu m} = \frac{\pi \times L}{40\,000} \times \left(d + \frac{50\,L}{T}\right)^2$$

where d = top diameter in cm
L = length in m
T = taper (e.g. 120)

An approximate volume can be read from the appropriate alignment chart (Figures 4, 5 or 6).

Sawlog volumes (i.e. a taper of 1:120) can also be read from a plastic diameter measuring rule which is available from forestry suppliers.

Notes

a. This method should not be used for sawlogs longer than 8.1 m as the possible percentage error increases rapidly with length; nor for hardwood logs.
b. The published sawlog tables give the volumes for the average diameter of the rounded down 2 cm diameter class, and so the formula and the alignment chart will not give the same results unless this convention is observed.

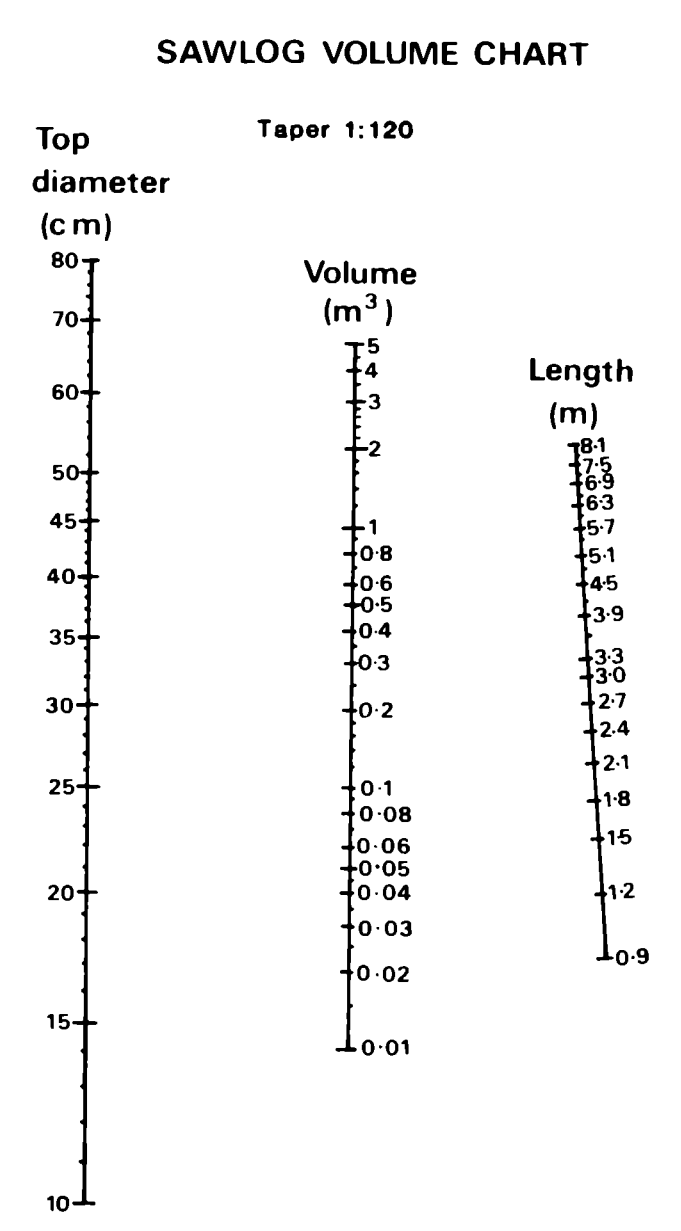


Figure 4 Sawlog volume chart

Further information on the top diameter method of measurement is given in the *Forest Mensuration Handbook*, Part III, Procedures 2, 3 and 4, pp. 22–26 and in the Top Diameter Tables.

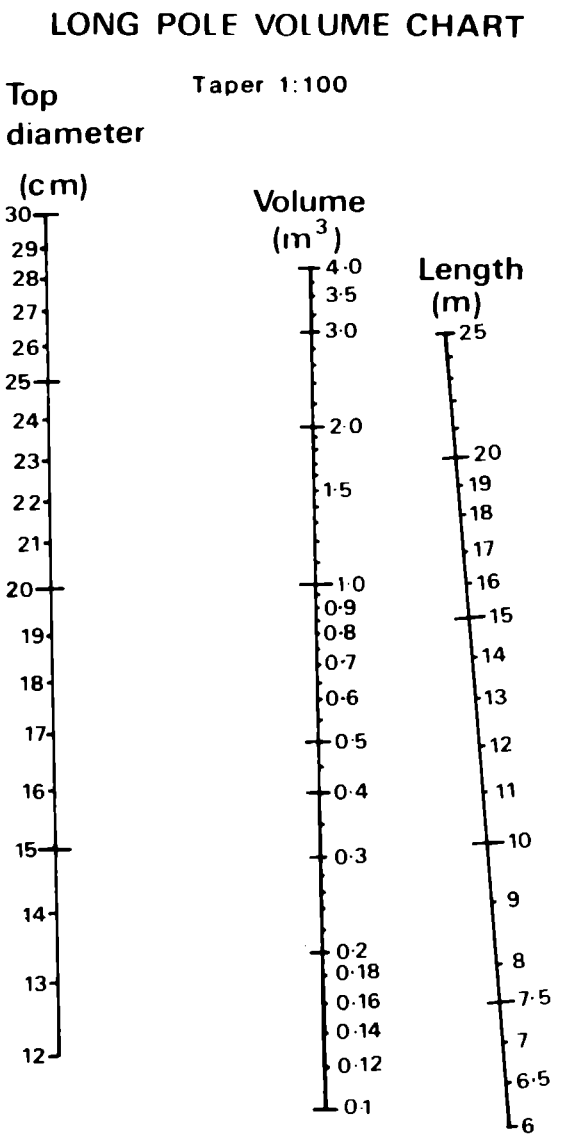


Figure 5 Long pole volume chart

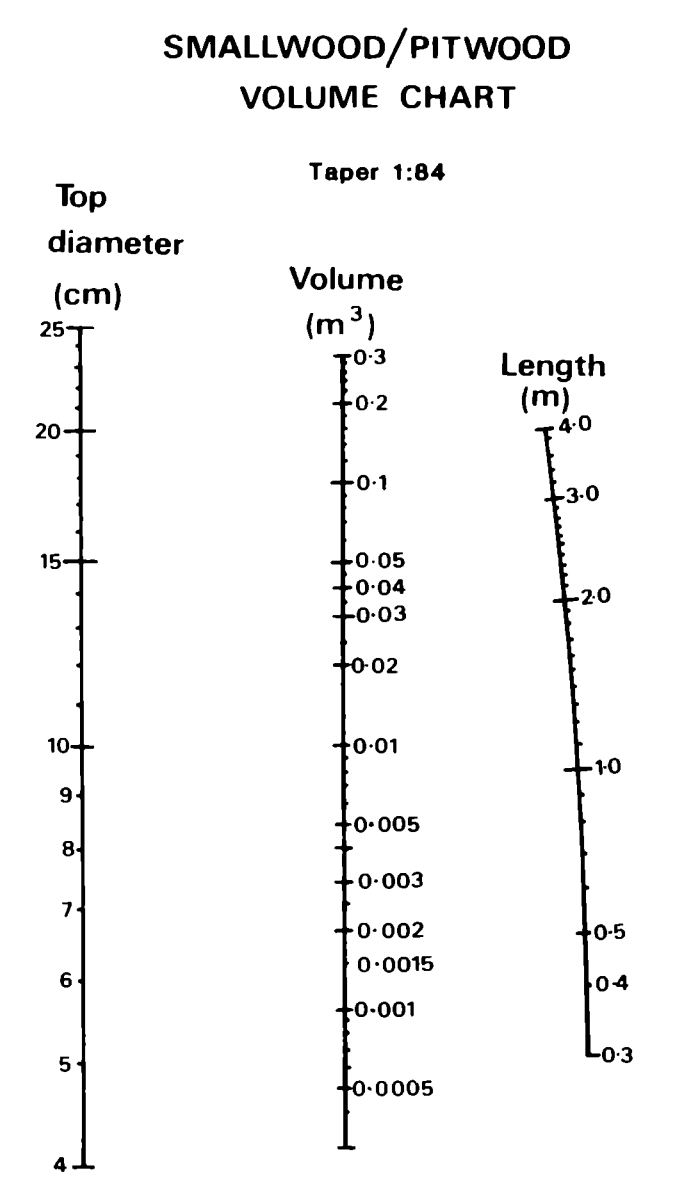


Figure 6 Smallwood/Pitwood volume chart

Stacked timber

This method for estimating the *solid volume* of timber (i.e. the volume of timber, excluding air spaces) can only be used with stacks of timber of *uniform length*. It works best with straight logs which are stacked neatly.

The overall volume of a stack, which is called the *stacked volume*, is rarely used in sales in Britain because the volume varies with the method of stacking. Sales by stacked measure are more common in the rest of Europe, where a stacked cubic metre is called a 'stere'.

The first step is to estimate an appropriate *solid/stacked conversion factor*. This must be estimated separately for different timber specifications, for different methods of stacking, and for different types of tree. The conversion factor will vary with many factors, including the lengths of the logs, their straightness and smoothness, their taper, their diameter, and the method of stacking. Conversion factors might be expected to be about 0.55–0.65 for broadleaved timber; 0.65–0.75 for average quality coniferous timber; and 0.75–0.85 for short, straight good quality coniferous timber. The theoretical maximum factor is 0.91.

There are two ways of estimating a solid/stacked conversion factor.

a. i. Measure the stacked volume.
   ii. Measure the volume of each piece using the mid diameter method (page 52), the end diameters method (page 51), or the top diameter method (page 54). The stack may have to be dismantled for this measurement.
   iii. Add these up to give the total solid volume.
   iv. Divide by the stacked volume to give the conversion factor.

b. i. Place a rectangular grid against the face of the stack, or against a photograph of the face of the stack.
   ii. Count the number of intersections which are on the ends of logs.
   iii. Divide by the total number of intersections to give the conversion factor.

A separate conversion factor should be estimated for several stacks, and the average of these taken as the correct solid/stacked conversion factor. Table 21 gives guidance as to the number of stacks which should be measured for a required level of precision.

Table 21 Number of samples for estimating solid/stacked conversion factors

		Total number of stacks					
		5	10	20	40	70	100
Uniform stacks (Coefficient of variation) about 5%)	Estimate ±2%	5	8	12	16	18	20
	Estimate ±4%	3	4	5	6	6	6
Average stacks (Coefficient of variation about 10%)	Estimate ±4%	5	8	12	16	18	20

This conversion factor is then used to estimate the solid volume of the remaining stacks of similar timber. The stacked volume should be multiplied by the solid/stacked conversion factor to give the solid volume.

Warning: A solid/stacked conversion factor *must* be worked out. An estimated or guessed average factor should not be used.

Further information on the measurement of stacked timber is given in the *Forest Mensuration Handbook*, Part III, Procedure 5, pp. 27–35.

Weight measurement

The volume of a load can be estimated by multiplying its weight (see page 14) by its volume/weight ratio. Unfortunately, the volume/weight ratio not only varies with region, species, individual trees and diameter, but also with the season, and the delay between felling and weighing. It is therefore essential to measure sample loads throughout any period for which estimates of volume from weight are required.

The volume/weight ratio should be estimated for every 'n'th load, where n is either read from Table 22, or calculated by the method described in the *Forest Mensuration Handbook*, pp. 42–43.

The solid volume of each sample load (i.e. the volume of timber in the load, excluding air spaces) has to be worked out using one of the two methods given opposite. The average volume/weight ratio can then be applied to the whole period, or the individual volume/weight ratios can be applied to their own small group of loads, whichever is the more convenient.

Table 22 Frequency of sample loads

	Desired confidence limits	Total number of loads			
		10	20	50	100
Pines					
(coefficient of	±2%	ALL	1:2	1:3	1:5
variation of 5%)	±4%	1:3	1:4	1:9	1:17
	±6%	1:5	1:8	1:19	1:37
	±8%	1:7	1:14	1:33	1:65
Other conifers					
(coefficient of	±2%	ALL	ALL	ALL	1:2
variation of 10%)	±4%	ALL	1:2	1:3	1:5
	±6%	1:2	1:3	1:6	1:10
	±8%	1:3	1:4	1:9	1:17

Method 1

If all the logs in the load are the same length, this will usually be the easiest way to calculate the solid volume of the load.

a. Measure the stacked volume.
b. Multiply this by the solid/stacked conversion factor determined as described on pages 58–59.

This method makes use of the fact that although the volume/weight ratio may vary considerably over a period, the solid/stacked conversion factor will remain the same while the harvesting team are working the same produce in similar stands by the same methods.

Method 2

This method can be used for any load of timber.

a. Measure the volume of each piece using the mid diameter method (page 52), the end diameters method (page 51), or the top diameter method (page 54).
b. Add these up to give the total solid volume.

The measurement can be done before the timber is loaded, while it is being loaded, after it has been unloaded, or even while it is in the load, although the measurement is usually more difficult in the latter case.

Further information on measurement by weight is given in the *Forest Mensuration Handbook*, Part III, Procedure 6, pp. 36–43.

Index

Further information is available from:

1. Forestry Commission Publications
   Handbook 6 Forestry Practice (1991)
   Field Book 1 Top Diameter Sawlog Tables (1987)
   Field Book 11 Mid Diameter Volume Tables (1990)
   Booklet 39 Forest Mensuration (1985)
   Booklet 48 Yield Models for Forest Management (1981)
   These can be obtained from the Forestry Commission, P.O. Box 100, Fareham, Hampshire, PO14 2SX.
   Tel: 01329 331345 Fax: 01329 330034
   E-mail: reception@telelink.co.uk
   A full list of Forestry Commission publications can be viewed on the Internet at http://www.forestry.gov.uk

2. Advice on any matter relating to timber measurement is available from the Mensuration Officer, Forest Research, Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH.
   Tel: 01420 22255.

Enquiries relating to this publication should be addressed to the Research Communications Officer, Forest Research, Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH.

ODC 52:562.22:242

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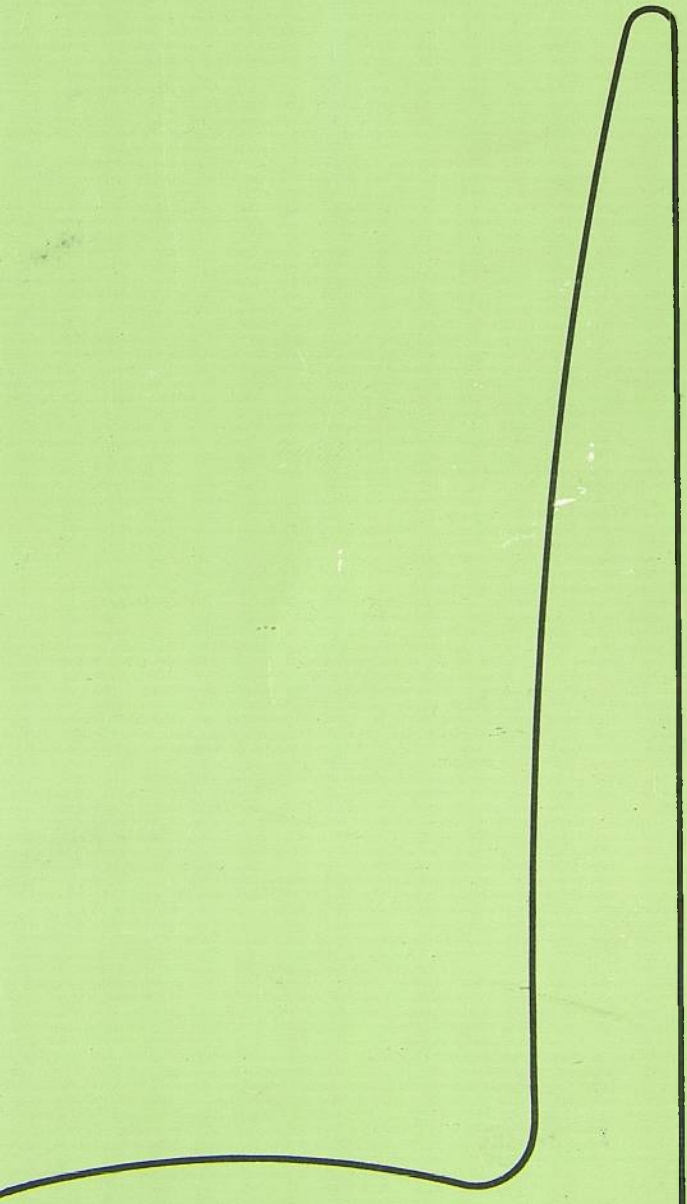

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