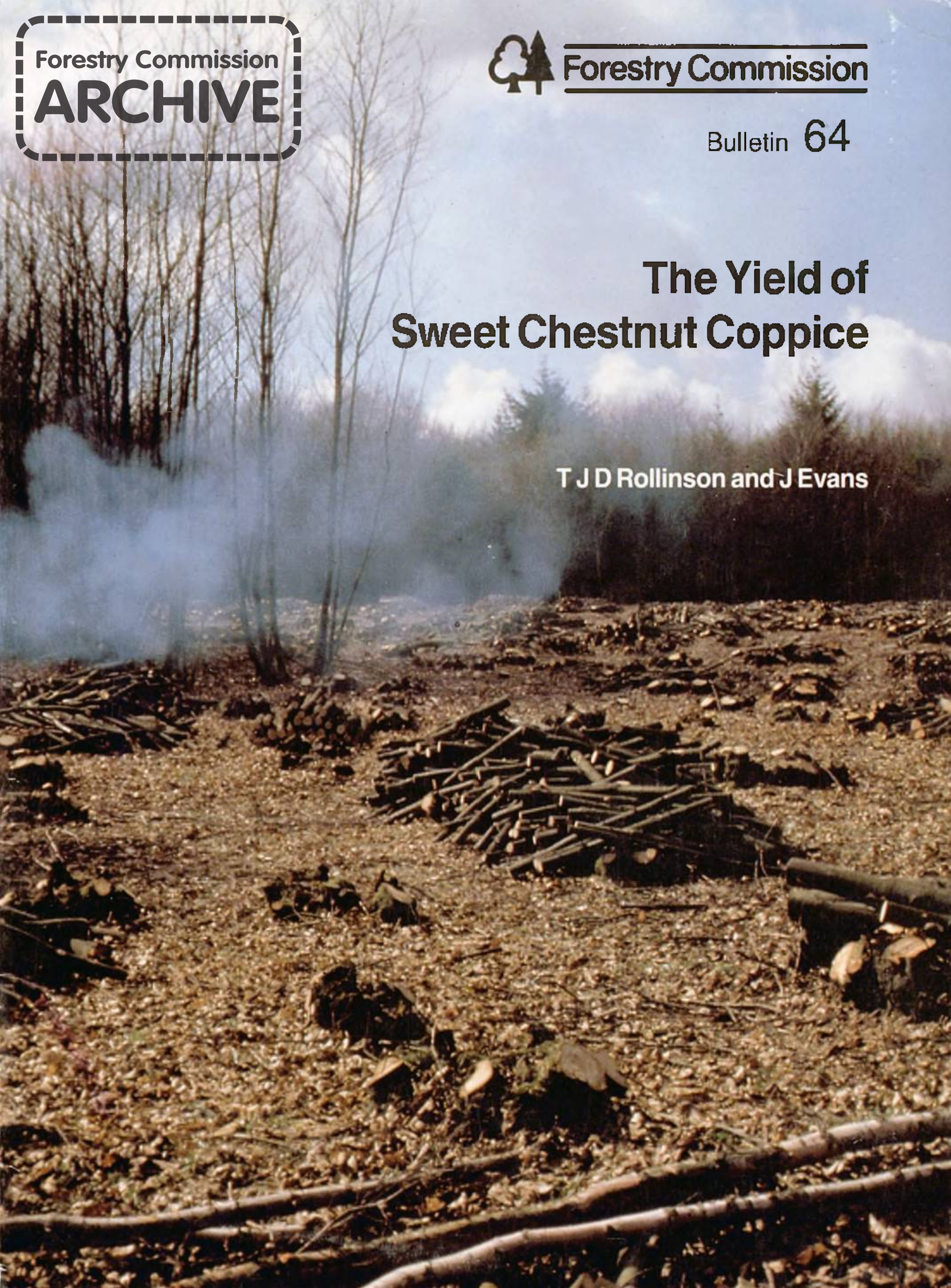
Forestry Commission

Bulletin 64

The Yield of Sweet Chestnut Coppice

T J D Rollinson and J Evans



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The Yield of Sweet Chestnut Coppice

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FRONT COVER: Harvesting 16-year-old Sweet chestnut coppice at King's Wood, Challock Forest, Kent. (*J. Evans*)

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Contents

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Introduction

Sweet chestnut (*Castanea sativa* Mill.) is the most important commercial coppice crop in Britain. Just over 19 000 hectares are currently worked almost wholly in south-east England where it is an important rural industry. Apart from the papers by Begley (1955) and Ford and Newbould (1970) on dry matter production of Sweet chestnut, there is little published information about the growth and yield of chestnut coppice crops in Britain.

This Bulletin reports on coppice growth and yield in relation to site and various stand characteristics and shows how volume or weight per hectare may be predicted from very simple measurements.

A general account of all types of coppice will be found in Forestry Commission Leaflet 83 (Crowther and Evans, 1986).

Areas

Table 1 shows the areas of Sweet chestnut coppice by region and type of coppice. The total area and distribution by counties has changed very little since the 1947 Census of Woodlands.

Table 1. Areas of Sweet chestnut coppice by region and type (in hectares)

Region	Coppice type		
	Simple	With standards	Total
Kent	9 163	3 381	12 544
E. Sussex	2 334	1 015	3 349
W. Sussex	1 102	291	1 393
Elsewhere in S.E. England	681	99	780
S.W. England	360	39	399
E. England	159	425	584
Northern England	17	25	42
Wales	–	–	–
Scotland	–	–	–
Totals	13 816	5 275	19 091

Source: Reports of the Forestry Commission Census of Woodlands and Trees, 1979-82.

Aspects of Coppice Management

Working practices

Working practices in Sweet chestnut coppice have been described recently in three Forestry Commission publications: Research Information Note 70/82/SILS (Evans, 1982), Leaflet 83 (Crowther and Evans, 1986) and Bulletin 62 (Evans, 1984). However, several aspects of coppice working have a direct bearing on growth and yield.

Sites

Sweet chestnut coppice is almost wholly confined to south-east England where the climate is relatively warm and sunny and rainfall is in the range 500-850 mm per year. Although there is some evidence of variation in growth in relation to soil type (e.g. growth is poor on poorly drained or insufficiently acid soils, the ideal being pH 4.0-4.5) the restricted distribution of commercial chestnut coppice in Britain probably explains the lack of large differences between crops in height growth *(Figure 3)*.

Thinning

Chestnut coppice is not thinned. From limited evidence with other species (e.g. Harris, 1956) artificial reduction of shoots on a stool will stimulate girth increment of the remainder but will also lead to some depression of overall increment per hectare.

Rotation

Most chestnut coppice is worked on a rotation length of between 10 and 20 years and the bulk about 12-16 years. This rotation length is well short of the age when mean annual volume increment culminates.

Rotation length is wholly determined by the technical requirements of markets. These remain primarily hop poles and cleft fence palings, the requirements for which are stem diameters of 7-10 cm. Areas of chestnut at rotation age are visually judged for the quantities of such products they will produce and, although total volume per hectare is taken into account indirectly, much the most important criteria are the number of *straight* stems and internode length.

Long term productivity

Most chestnut coppices were established in the middle of the last century and thus will have been worked for 6-9 rotations. In principle this continuous working could lead to declining yields with time because of two factors, site exhaustion and stool mortality.

Although the regular removal of biomass from site may cause net loss of nutrients over time there is no recorded evidence of any fall-off in yield so far. However, in fertiliser experiments which have included the addition of phosphate, a nutrient which could be expected to be depleted over several coppicings, measurable improvement in growth was recorded in one instance (see below).

More important as a potential cause of yield decline is stump death. Provided shoots emerge there is no evidence that the vigour of shoot growth is affected by the number of previous coppicings but stump mortality itself can reduce yield per hectare if stocking is greatly reduced to, say, less than 500 stumps per ha. In chestnut coppice about one stump in 20 dies at each cutting. An important part of coppice working is to make good the gaps which result, either by planting or by layering an adjacent shoot.

Recent silvicultural research

Three experiments established since 1980 have been designed to influence coppice productivity. Two involve application of fertilisers, either phosphate or lime or a combination of the two, to stimulate growth. On one site phosphate fertilising in 10-year-old coppice led to a significant increase in stem diameter but on both sites the heavy application of lime (2 tonnes per ha) depressed increment (Evans, 1986). The third experiment, only established in 1985, is investigating the effects of thinning coppice shoots on a stool at different times in the rotation and whether pruning of shoots (dressing) measurably improves quality.

Future of Sweet chestnut coppice

Prices for chestnut coppice vary markedly from year to year but, nevertheless, continuing demand for coppice products has been a feature of the chestnut coppice industry. There is no reason why this should not continue and, with the increasing interest in firewood, demand can be expected to be maintained. In general, crops are found to give comparable net discounted revenues to those of Corsican pine of yield class 12-14.

Yield of Sweet Chestnut Coppice

Previous work

The production of coppice biomass in Britain has received little study. Begley (1955) published information on total production as measured in terms of volume and weight yields per unit area, and also in terms of out-turn of prepared produce (including posts, pales, pea sticks and roundwood waste). However, Begley's study was limited to three 16-year-old stands and one 17-year-old stand in Kent. Ford and Newbould (1970) published information on dry weight production from younger stands of managed coppice covering 1 to 18-year-old crops but confined to just one site in Kent.

The need for biomass data

In recent years forest researchers have become increasingly interested in the estimation of the volume and weight of all components of single trees and forest stands. Two factors have been particularly important: firstly, the oil price rises of the 1970s which focussed attention on the use of wood as a renewable source of energy and, secondly, the interest of ecological researchers in the total production of plant material in forest ecosystems. Knowledge of the total production of components other than just stemwood of Sweet chestnut coppice stands is important because those involved in working coppice actually use far more than just this part of the tree.

Survey methods

The object of the work was twofold: firstly, to estimate volume and weight yields of Sweet chestnut coppice of different ages over a range of sites in southern England and, secondly, to find some method for estimating yield per hectare from very simple field measurements. Field sampling was undertaken in two stages. In stage 1 basic information was collected on stocking density, height, basal area and mean diameter. In stage 2 stands were felled and measured to estimate biomass production for different stand components.

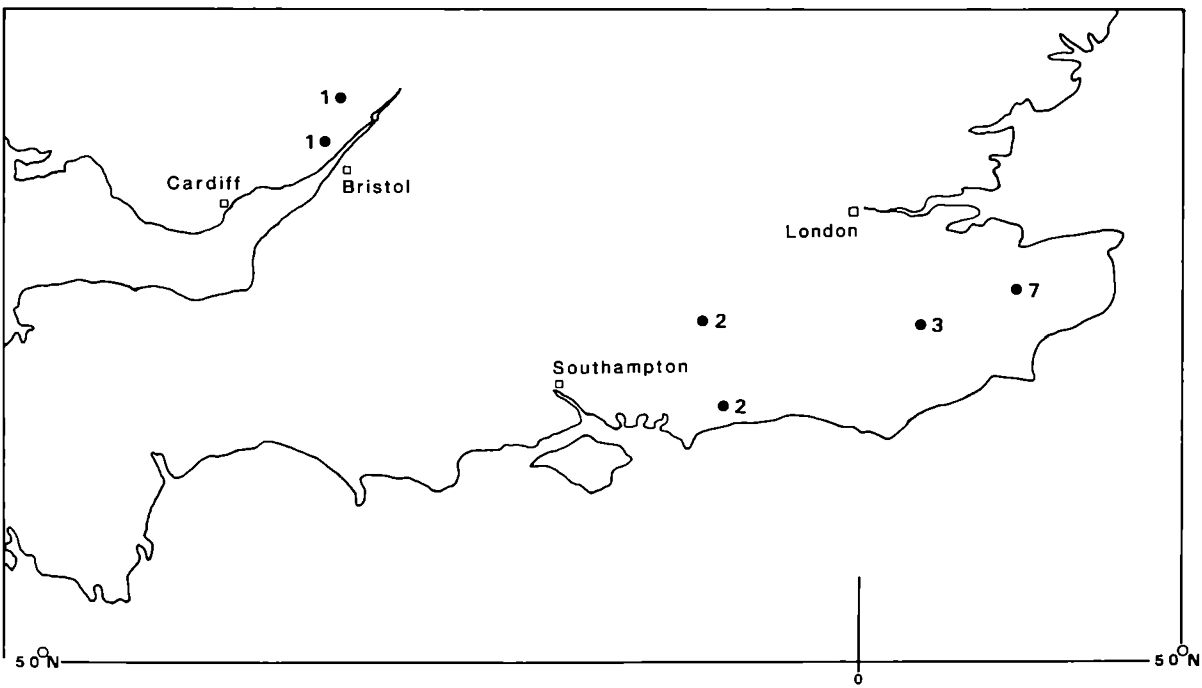
Stage 1

Sixteen stands covering a range of sites, ages and stocking densities were sampled. Stands were selected broadly to represent the geographical distribution of Sweet chestnut coppice in southern England. Coppice stands were subdivided into four age classes, and four sub-compartments were selected in each age class to cover relatively good and poor sites in terms of perceived vigour. Figure 1 shows the approximate location of the 16 stands.

Stage 2

Twelve stands were sampled for biomass estimation. Ten of the stands were selected from the Stage 1 samples and two additional stands in 3 and 4-year-old coppice were sampled. The choice of Stage 1 stands for sampling in Stage 2 was purely a matter of convenience as the Stage 1 stands covered a broad spread of ages. The Stage 2 plots were located at random in each stand. Details of survey methods, data collected and calculations of results are given in the Appendix.

Figure 1. Location in southern Britain of stands sampled in Stage 1 (numbers indicate the number of samples taken at each site).



Results

Stage 1

Table 2 below shows the forest location and age of the 16 stands sampled in Stage 1.

Table 2. Stage 1 sample plots – forest location and age

Stand	Forest	Age (years)
A1	Arundel	8
C1	Challock	9
B1	Bedgebury	10
C2	Challock	10
AH1	Alice Holt	12
AH2	Alice Holt	13
C3	Challock	13
B2	Bedgebury	14
B3	Bedgebury	16
C4	Challock	16
C5	Challock	18
D1	Dean	19
C6	Challock	20
A2	Arundel	21
C7	Challock	23
D2	Dean	28

Table 3 gives a summary of the Stage 1 data collected at each of the 16 sites.

Figure 2 shows how the number of shoots per hectare falls with increasing age for the 16 stands sampled.

Figure 3 shows dominant height growth for 15 of the 16 stands (one stand was not measured). Each line represents the growth in dominant height, that is of the largest diameter shoots on the stools measured. The height growth of the sites sampled shows some differentiation into height classes but this was not considered to be sufficient to require stratification for sampling in Stage 2. Nevertheless, in Stage 2, sites were chosen to represent a range of fertilities.

Figure 2. Number of shoots per hectare in relation to age. Stage 1 stands.

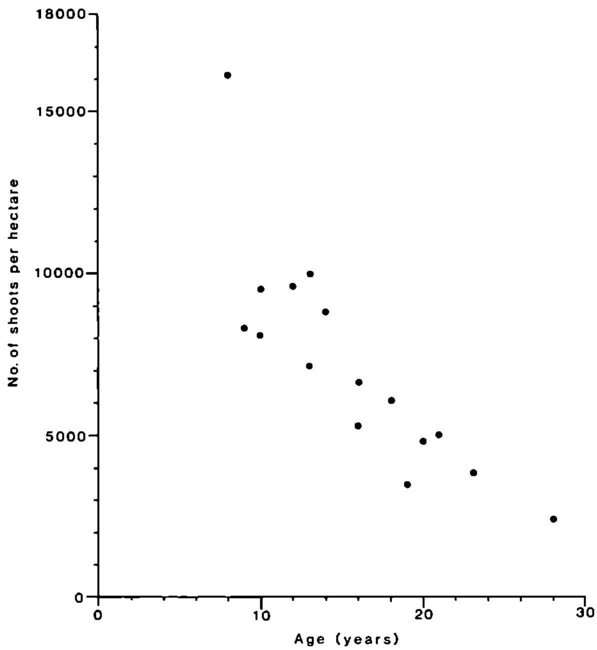


Figure 3. The growth in dominant height for 15 of the 16 Stage 1 stands.

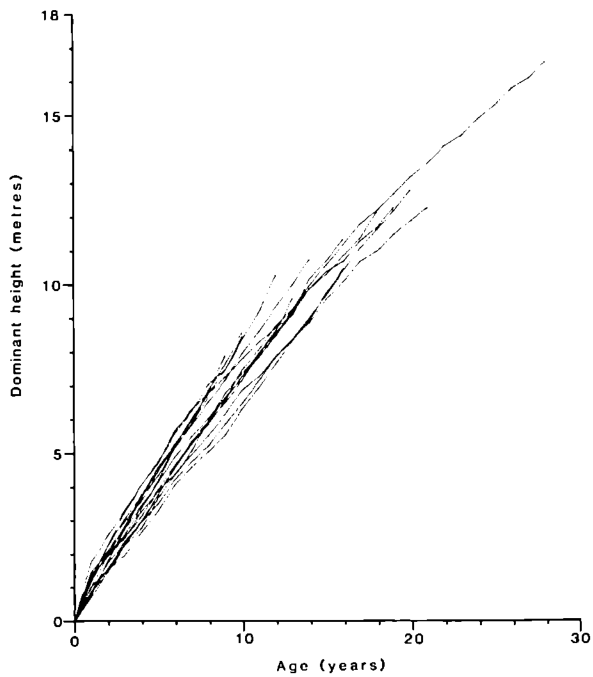


Table 3. Stage 1 stands – summary of measurements

Stand	Age (years)	Number of live stools per ha	Number of live shoots per ha	Average number of live shoots per stool	Average dbh of live shoots (cm)	Dbh range of live shoots (cm)	Basal area of live shoots per ha (m^2)	Average height of largest shoots (m)*	Average diameter of live stools (m)
A1	8	1940	16120	8	4.3	0.5- 9.0	23.0	6.7	1.7
C1	9	760	8360	11	5.7	1.2-15.3	21.7	8.3	1.6
B1	10	1060	9540	9	6.0	1.4-13.0	27.0	9.6	1.0
C2	10	900	8060	9	6.6	2.0-13.4	27.8	9.9	1.0
AH1	12	1980	9620	5	6.4	2.3-17.4	30.7	9.5	1.0
AH2	13	1800	10000	6	6.8	1.8-13.2	36.7	11.3	1.2
C3	13	840	7120	8	6.9	1.6-14.2	26.3	10.5	1.1
B2	14	1000	8840	9	7.2	1.3-17.6	36.2	11.1	1.0
B3	16	1120	6660	6	8.2	1.5-19.3	35.5	12.6	1.0
C4	16	720	5300	7	8.7	2.5-17.3	31.8	10.8	1.3
C5	18	840	6080	7	9.0	2.0-18.4	38.5	12.8	1.2
D1	19	800	3480	4	11.8	3.0-21.7	38.1	12.6	0.9
C6	20	720	4820	7	10.9	4.0-19.0	44.6	13.6	0.9
A2	21	640	5000	8	9.9	2.3-18.4	38.7	13.1	1.1
C7	23	680	3880	6	12.7	4.0-24.3	49.4	13.5	1.1
D2	28	540	2420	4	14.9	1.0-22.3	42.0	17.5	1.0

* The average height of the shoots of largest dbh in each of the five plots.

Stage 2

Table 4 below gives information about the 12 stands sampled in Stage 2.

Table 4. Stage 2 sample plots – forest location and age

Stand	Forest	Age (years)
AH3	Alice Holt	3
AH4	Alice Holt	4
A1	Arundel	8
C1	Challock	9
AH1	Alice Holt	12
B2	Bedgebury	14
B3	Bedgebury	16
C5	Challock	18
D1	Dean	19
A2	Arundel	21
C7	Challock	23
D2	Dean	28

A comparison of the summary measurements between stands sampled in both Stage 1 and Stage 2 shows quite wide variation in some cases. However, the Stage 2 samples were located at random and were not intended necessarily to be representative of the Stage 1 samples.

Table 5 gives a summary of the Stage 2 data collected at each of the 12 sites.

Volumes

Table 6 shows estimated volumes per hectare and mean annual volume increments for the 12 sites. Volumes and mean annual increments are shown to 4 and 7 cm top diameter over bark (tdob).

The 3 and 4-year-old crops at Alice Holt have no stems greater than 7 cm dbh (diameter at breast height of 1.3 m). Volumes to 7 cm for the other sites varied from 1.3 m³ per ha for an 8-year-old crop to 353.2 m³ per ha for a 28-year-old crop. Figure 4 shows volume to 7 cm top diameter over bark plotted against age for the 12 sites.

Table 6. Stage 2 plots – fresh felled volume of timber

Plot	Age (years)	Estimated volume (m^3/ha)		Mean annual volume increment (m^3/ha/year)	
		To 4 cm top diam.	To 7 cm top diam.	To 4 cm top diam.	To 7 cm top diam.
AH3	3	–	–	–	–
AH4	4	3.6	–	0.9	–
A1	8	37.6	1.3	4.7	0.2
C1	9	55.8	24.5	6.2	2.7
AH1	12	107.3	48.4	8.9	4.0
B2	14	105.0	66.6	7.5	4.8
B3	16	125.1	63.1	7.8	3.9
C5	18	220.1	170.8	12.2	9.5
D1	19	197.7	160.8	10.4	8.5
A2	21	190.3	148.8	9.1	7.1
C7	23	252.8	218.1	11.0	9.5
D2	28	366.7	353.2	13.1	12.6

Figure 4. Volume production to 7 cm top diameter over bark in relation to age. Stage 2 plots.

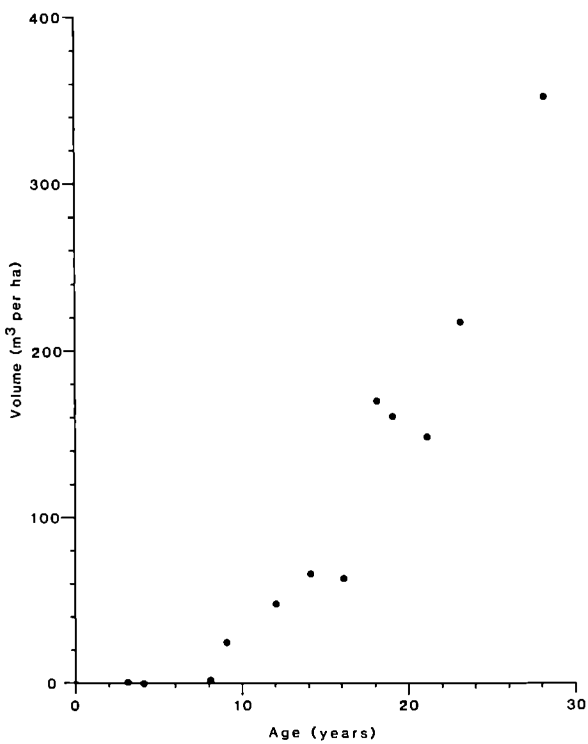


Table 5. Stage 2 plots – summary of measurements

Plot	Age (years)	Number of live stools in plot	Number of live shoots in plot	Average number of live shoots per stool	Average dbh of live shoots (cm)	Dbh range of live shoots (cm)	Basal area of live shoots in plot (m^2)
AH3	3	8	190	24	1.3	0.2- 2.6	0.025
AH4	4	10	111	11	2.6	0.3- 5.2	0.060
A1	8	27	137	5	4.4	0.9- 7.4	0.208
C1	9	9	59	7	6.3	1.3-10.8	0.183
AH1	12	23	70	3	6.9	3.6-11.1	0.260
B2	14	12	65	5	7.1	0.9-11.9	0.257
B3	16	10	82	8	7.2	2.3-12.2	0.331
C5	18	9	57	6	9.8	2.6-15.6	0.429
D1	19	9	52	6	9.9	3.9-18.1	0.405
A2	21	7	46	7	10.4	1.6-18.1	0.387
C7	23	7	37	5	12.8	5.5-22.3	0.478
D2	28	4	18	5	20.5	11.1-33.9	0.597

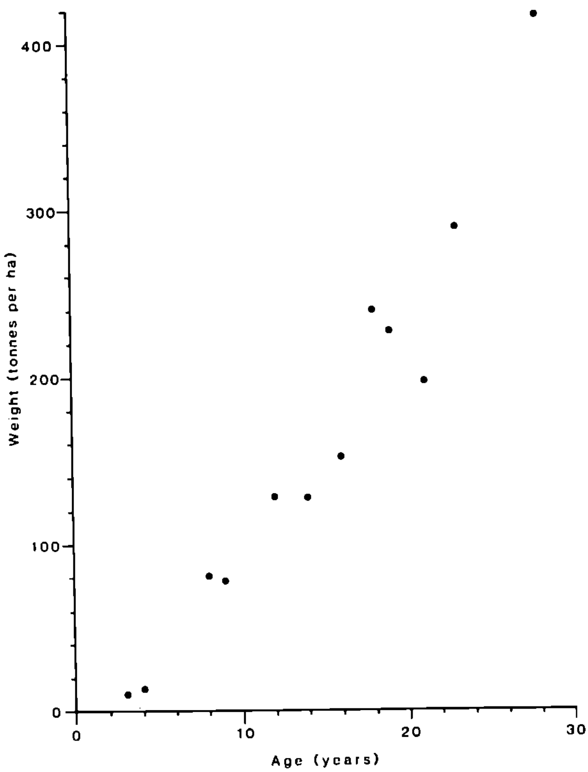
Note: All plots were 0.01 ha in size.

Fresh weights

Table 7 shows estimated fresh felled weights per hectare for the 12 sites. Weights are shown to 4 and 7 cm top diameter and also the weight of stems less than 4 cm dbh, the weight of tops and branches and the total fresh weight of these components.

Total fresh weight yields including all stems, tops and branchwood but excluding leaves ranged from 9.36 to 415.93 tonnes per hectare. Figure 5 shows total fresh weight plotted against age for the 12 sites.

Figure 5. Total fresh weight of stems, tops and branches in relation to age. Stage 2 plots.



Moisture content

Table 8 shows moisture content for breast height discs from stems greater than 4 cm dbh and for branchwood and tops for each of the 12 sites.

Moisture contents of stemwood vary from 82.4 to 107.7%. The average for all sites is 98.0%. This compares with Begley's (1955) figure of 100%. Moisture content was assessed at several heights along the stem as well as at breast height. An analysis of variation along the stem at three sites: Alice Holt, AH3 (3 years), Bedgebury, B2 (14 years), and Challock, C7 (23 years) showed that moisture content of discs at the butt of stems and at any other height were significantly different. In all cases moisture content decreases with height up the shoot and generally increases with the size of the shoot, although this increase tends to be more significant over the smaller end of the size range. Moisture content of branchwood is always lower than moisture content of stemwood.

Table 8. Stage 2 plots – moisture content

Plot	Age (years)	Moisture content (%) Breast height discs	Moisture content (%) Branchwood and tops
AH3	3	–	106.7
AH4	4	103.8	100.4
A1	8	90.5	84.6
C1	9	105.5	97.0
AH1	12	107.7	83.4
B2	14	87.8	84.8
B3	16	98.8	92.5
C5	18	100.6	89.6
D1	19	98.7	84.3
A2	21	82.4	81.0
C7	23	101.5	90.1
D2	28	100.6	83.4

Density

Green (or fresh felled) density is the weight of green wood per unit of green volume. Basic density is the weight of oven dried wood per unit of green volume.

Table 9 shows mean green density and mean basic density for breast height discs from stems greater than 4 cm dbh for each of the 12 sites.

Green density of stemwood varies from 0.796 to 1.018 g/cc. The average for all sites is 0.896 g/cc. Green density was found to decline up the stem and significant differences ($p < 0.05$) were found between discs cut at the base, breast height and the centre of the stems. However, there were no significant differences between trees of different sizes. Basic density of stemwood varies from 0.394 to 0.544 g/cc. The average for all sites is 0.472 g/cc. There were no significant differences in basic density between trees of different sizes or between discs cut at different heights. Table 9 indicates, however, that there are differences in both green and basic density between different sites.

Table 7. Stage 2 plots – fresh felled weights

Plot	Age (years)	Estimated weight in tonnes/hectare					Mean annual weight increment (tonnes/ha/year)	
		Stems <4 cm dbh	To 4 cm top diam.	To 7 cm top diam.	Tops and branches	Total weight*	To 7 cm	Total weight
AH3	3	9.36	–	–	–	9.36	–	3.1
AH4	4	8.44	2.54	–	2.64	13.62	–	3.4
A1	8	14.20	37.13	1.56	29.30	80.63	0.2	10.1
C1	9	4.42	56.26	26.49	16.75	77.43	2.9	8.6
AH1	12	1.21	95.76	44.42	31.16	128.13	3.7	10.7
B2	14	3.75	101.55	66.13	21.57	126.87	4.7	9.1
B3	16	3.37	121.60	61.15	27.03	152.00	3.8	9.5
C5	18	0.68	208.21	165.78	30.76	239.65	9.2	13.3
D1	19	2.00	190.31	156.84	34.56	226.87	8.3	11.9
A2	21	–	170.72	132.30	26.73	197.45	6.3	9.4
C7	23	–	259.59	229.44	28.93	288.52	10.0	12.5
D2	28	–	361.96	348.38	53.97	415.93	12.4	14.9

* Total weight is the sum of the three columns: 'weight of stems <4 cm dbh', 'weight up to 4 cm top diameter' and 'weight of tops and branches'. See definitions in the Appendix, pp. 19-20

Table 9. Stage 2 plots – green density and basic density

Plot	Age (years)	Mean green density (g/cc)	Mean basic density (g/cc)
AH3	3	–	–
AH4	4	1.018	0.544
A1	8	0.799	0.453
C1	9	0.951	0.474
AH1	12	0.796	0.394
B2	14	0.933	0.506
B3	16	0.897	0.477
C5	18	0.911	0.477
D1	19	0.866	0.457
A2	21	0.870	0.494
C7	23	0.942	0.482
D2	28	0.869	0.435

Volume/weight relationships

Given the green density of a stand the volume/weight ratio can be derived as $\frac{1}{\text{green density}}$. For all plots combined the average green density was 0.896 g/cc which gives a volume/weight ratio of 1.116 m^3 per tonne. As a separate exercise the individual plot values for volume and fresh weight to 4 and to 7 cm tdob were investigated. Figure 6 shows volume to 7 cm tdob plotted against fresh weight to 7 cm tdob with the regression line fitted.

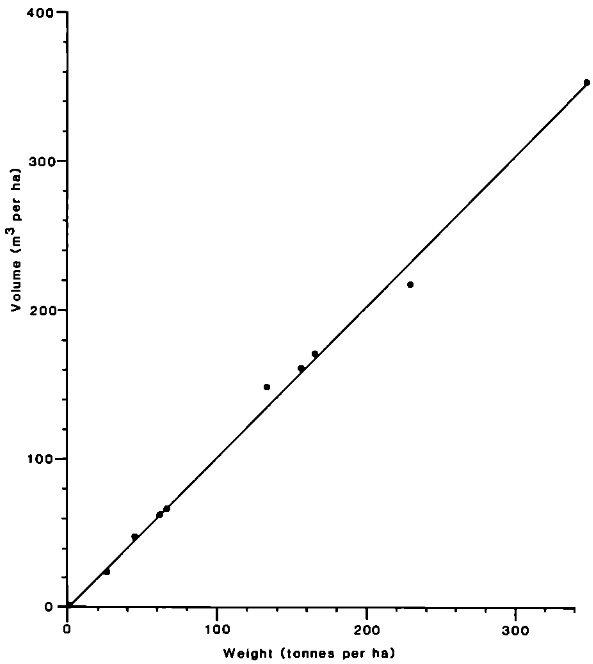
The regressions for volumes to 4 and 7 cm tdob have been constrained to pass through the origin and are as follows:

Volume to weight regressions	R^2	
$Volume_4 = 1.0261 \times Wt_4$	0.998	(1)
$Volume_7 = 1.0119 \times Wt_7$	0.998	(2)

where volume is in m^3 and fresh weight is in tonnes.

The correlation between volume and weight to stated top diameters is so good for the 16 sites that the regression functions above can be used for stands of all ages of Sweet chestnut coppice in southern Britain to estimate volume from weight or vice versa.

Figure 6. Relationship between volume to 7 cm top diameter over bark and fresh weight to 7 cm top diameter over bark, with regression line fitted.



Prediction of Volume or Weight from Simple Field Measurements

There has been very little work published on the estimation of yield from coppice crops. A major part of the sampling scheme devised for this work was to allow prediction of volume and weight yields using very simple field measurements. The estimation of volume and weight in each plot sampled involved considerable field work which most foresters managing coppice crops would find prohibitively expensive.

Regression analysis was used to predict volumes and weights from field measurements involving age, mean dbh, basal area, number of shoots per hectare and per stool and number of stems per hectare. The addition of some measure of stocking density made very little improvement to the overall model fits, so it was decided to restrict the choice of variables to those which require only simple field measurement, and the final choice was to use age, mean dbh and basal area. Of these, age is the simplest to estimate as the date the coppice was last cut is usually known. If not, it can be easily derived using little field work by felling a small number of stems and counting annual rings at the base. Mean diameter at breast height can be estimated easily in the field by measuring sample shoots; these can be chosen at random through the stand. Note that in this context mean diameter is in fact the diameter of a tree of mean basal area (also called the quadratic mean dbh). Basal area per hectare takes rather more time to measure as it involves measuring diameters in plots of known area or using a relascope. Figures 7, 8 and 9 show the regressions derived for estimating volume per hectare to 7 cm tdob from age, mean diameter and basal area measurements respectively. The regressions for estimating volume per hectare to 4 cm tdob, and weight per hectare to 4 and 7 cm tdob are very similar. The equations for these regressions are given in Table 10.

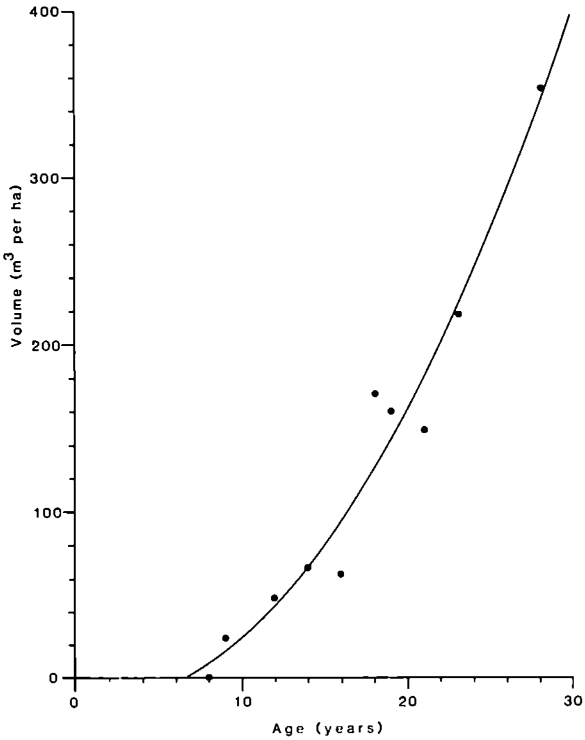


Figure 7. Relationship between volume to 7 cm top diameter over bark and age, with regression curve fitted.

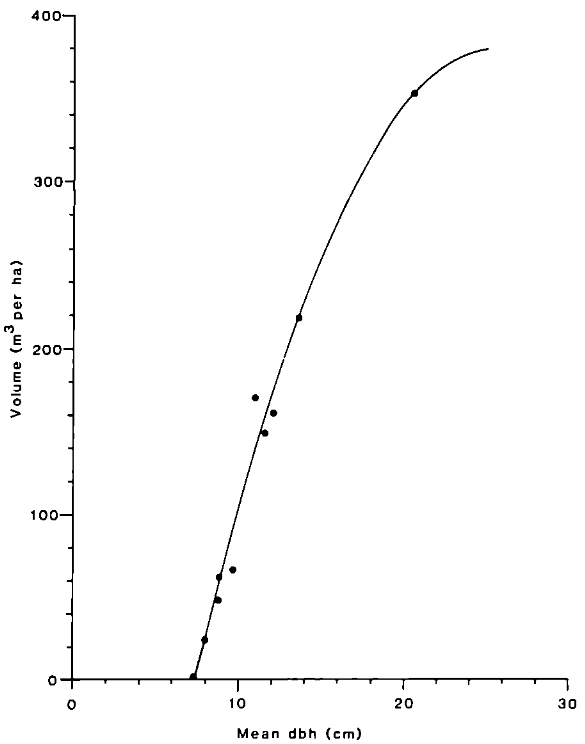
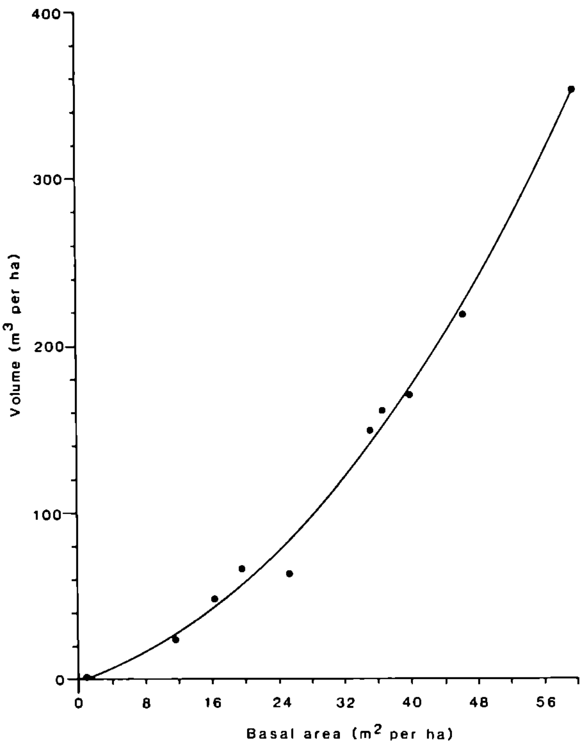


Figure 8. Relationship between volume to 7 cm top diameter over bark and mean dbh of stems with a diameter greater than or equal to 7 cm over bark, with regression curve fitted.

Figure 9. Relationship between volume to 7 cm top diameter over bark and basal area of stems with a diameter greater than or equal to 7 cm over bark, with regression curve fitted.



For practical use the regressions using age alone are likely to be quite satisfactory. For more precise work, mean diameter should be measured and for more accurate estimates still the use of basal area is recommended. Note that in these regressions, where volume or weight are estimated to 4 cm tdob, the mean diameters and basal areas refer to all coppice stems in the stand with a diameter greater than or equal to 4 cm ob. Similarly where volume or weight are estimated to 7 cm tdob, the mean diameters and basal area are for coppice stems with a diameter greater than or equal to 7 cm ob. Methods for estimating mean diameter and basal area per hectare are described in Forestry Commission Booklet 49 (1983) and are applicable to coppice. For practical use these regressions should only be used in the following conditions:

For even-aged stands of Sweet chestnut coppice containing less than 10% of other species.
Within the age range of 5-30 years.
Within the average dbh range 5-24 cm.
Within the basal area range 0-60 m²·ha.

Provisional yield table for Sweet chestnut coppice

Tables 11 and 12 give volumes and fresh weights of Sweet chestnut coppice for a range of ages and mean diameters of Sweet chestnut coppice stands. The tables are based on the regressions given in Table 10.

Table 11. Yield table based on age

Age	Volume (m³/ha)		Fresh weight (tonnes/ha)	
(years)	To 4 cm tdob	To 7 cm tdob	To 4 cm tdob	To 7 cm tdob
5	15	–	15	–
10	65	25	60	25
15	130	80	125	80
20	205	160	200	160
25	300	270	295	265
30	405	405	400	400

Table 12. Yield table based on mean diameters

Mean	Volume (m³/ha)		Fresh weight (tonnes/ha)	
diameter (cm)	To 4 cm tdob*	To 7 cm tdob†	To 4 cm tdob*	To 7 cm tdob†
5	20	–	20	–
7	95	–	90	–
9	160	65	150	60
11	215	135	210	135
13	260	200	255	200
15	300	255	295	250
17	330	300	325	295
19	355	335	350	330
21	370	360	370	355
23	375	375	375	370

* Use mean diameter of all coppice stems with a diameter equal to or greater than 4 cm ob.

† Use mean diameter of all coppice stems with a diameter equal to or greater than 7 cm ob.

Table 10. Regression equations for estimating volumes and weights of Sweet chestnut coppice from simple field measurements

To estimate	From	Use	R^2
VOLUME in m^3/ha to 4 cm tdob and above	AGE (years)	$V_4 = -24.9 + 6.48\,(age) + 0.257\,(age)^2$	0.953
	DBH (cm)	$V_4 = -194.4 + 48.23\,(dbh) - 1.017\,(dbh)^2$	0.974
	BASAL AREA (m^2/ha)	$V_4 = 2.16\,(BA) + 0.0672\,(BA)^2$	0.998
		where dbh and BA are for all trees with dbh $\geqslant$ 4 cm	
VOLUME in m^3/ha to 7 cm tdob and above	AGE (years)	$V_7 = -9.0 - 1.83\,(age) + 0.520\,(age)^2$	0.956
	DBH (cm)	$V_7 = -382.4 + 60.41\,(dbh) - 1.197\,(dbh)^2$	0.981
	BASAL AREA (m^2/ha)	$V_7 = 1.38\,(BA) + 0.0754\,(BA)^2$	0.997
		where dbh and BA are for all trees with dbh $\geqslant$ 7 cm	
FRESH WEIGHT in tonnes/ha to 4 cm tdob and above	AGE (years)	$WT_4 = -17.7 + 4.86\,(age) + 0.302\,(age)^2$	0.950
	DBH (cm)	$WT_4 = -188.4 + 46.15\,(dbh) - 0.937\,(dbh)^2$	0.977
	BASAL AREA (m^2/ha)	$WT_4 = 1.79\,(BA) + 0.0725\,(BA)^2$	0.998
		where dbh and BA are for all trees with dbh $\geqslant$ 4 cm	
FRESH WEIGHT in tonnes/ha to 7 cm tdob and above	AGE (years)	$WT_7 = 0.1 - 3.11\,(age) + 0.551\,(age)^2$	0.947
	DBH (cm)	$WT_7 = 380.5 + 59.80\,(dbh) - 1.182\,(dbh)^2$	0.977
	BASAL AREA (m^2/ha)	$WT_7 = 1.17\,(BA) + 0.0785\,(BA)^2$	0.997
		where dbh and BA are for all trees with dbh $\geqslant$ 7 cm	

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References

ALEMDAG, I.S. (1980). *Manual of data collection and processing for the development of forest biomass relationships.* Petawawa National Forestry Institute. Canadian Forestry Service. Information Report PI-X-4.

BEGLEY, C.D. (1955). *Growth and yield of Sweet chestnut coppice.* Forestry Commission Forest Record 30. HMSO, London.

CROWTHER, R.E. and EVANS, J. (1986). *Coppice.* Forestry Commission Leaflet 83 (2nd edition). HMSO, London.

EDWARDS, P.N. (1983). *Timber measurement – a field guide.* Forestry Commission Booklet 49. HMSO, London.

EVANS, J. (1982). *Sweet chestnut coppice.* Research Information Note 70/82/SILS. Forestry Commission, Edinburgh.

EVANS, J. (1984). *Silviculture of broadleaved woodland.* Forestry Commission Bulletin 62. HMSO, London.

EVANS, J. (1986). Nutrition experiments in broadleaved stands: II. Sweet chestnut and stored oak coppice. *Quarterly Journal of Forestry* **80** (2), 95-104.

FORD, E.D. and NEWBOULD, P.J. (1970). Stand structure and dry weight production through the Sweet chestnut (*Castanea sativa* Mill.) coppice cycle. *Journal of Ecology* **58**, 275-296.

FORESTRY COMMISSION (1976). *Sample plot code.* Internal code. Forestry Commission, Mensuration Branch, Alice Holt Lodge, Farnham, U.K.

HARRIS, L.G. (1956). Relative growth of coppice from a varying number of shoots per stool. *Quarterly Journal of Forestry* **50**, 244.

APPENDIX

Survey Methods

Stage 1

In each of the 16 stands five sample plots of 0.01 ha each were located at random. The following data were recorded in each plot:

1. number of live stools;
2. number of live shoots per stool;
3. diameter at breast height (dbh) of every live shoot measured at 1.3 m from ground level;
4. the height of the shoot of largest dbh on two randomly selected stools;
5. the height of the shoot of largest dbh in the plot;
6. the maximum and minimum diameters of two live stools randomly selected;
7. in the first, third and fifth plot in each subcompartment, one of the height trees measured in 4. above was felled and yearly height increments were measured. When annual shoot growth could no longer be identified the stem was cut into sections and the number of rings was counted at each cut and at the base of the shoot to estimate the age;
8. general information on the stand was collected, including elevation, aspect, soil type, precipitation, slope and a visual description of the condition of the crop and surface vegetation.

Stage 2

In each of the 12 stands sampled one 0.01 ha plot was located at random. The same information recorded in steps 1-6 for Stage 1 plots was collected for Stage 2 plots. In addition sample trees were felled, weighed and measured for volume according to the procedures described below:

1. Dbh measurements were recorded in 0.1 cm diameter classes and then subdivided into three categories: less than 4 cm, 4-6.9 cm and 7 cm and above. In each of these categories 15 shoots were sampled systematically through the diameter range to be used for estimating volume and weight. For some plots there were fewer than 15 shoots in each of the three diameter categories, so the maximum number of samples in any plot was 45 shoots.
2. Volume measurements were taken as follows:
   i. On sample shoots with a dbh of 7 cm or more the length of shoot to tip, to 4 cm and 7 cm top diameter over bark (tdob) and the mid diameter of the length from butt to 7 cm tdob were measured.
   ii. On sample shoots with a dbh between 4-6.9 cm the length to tip and to 4 cm and the mid diameter of the length from butt to 4 cm tdob were measured.
   iii. Volume was not measured for shoots with a diameter less than 4 cm.

All measurements were taken overbark.

3. Fresh felled weight measurements were taken as follows:

   All sample shoots in the plot were weighed using a spring balance on site. Measurements were recorded individually for each stool. Shoots were divided into material less than 4 cm dbh (including small shoots); branches and tops; shoot material with a dbh between 4-6.9 cm; and shoot material greater than or equal to 7 cm dbh.

4. Moisture content and density measurements were sampled following the procedure suggested by Alemdag (1980):
   i. On sample shoots greater than 4 cm dbh, sections were cut from the stem at the butt, breast height,

mid point, half way between mid point and 7 cm diameter and either half way between 7 cm and 4 cm diameter or at the top of the stem.

ii. On sample shoots less than 4 cm and branchwood and tops, a sample 30 cm in length was cut from the centre of a bundle of shoots and tops.

Samples were placed immediately into polythene bags and taken back to the laboratory and placed in cold storage.

a) For sample shoots greater than 4 cm dbh, a 4 cm thick disc was cut from the centre of the sample section. A wedge approximately 30° was cut out of each disc. The remaining part of the disc was weighed including bark to obtain fresh weight, then labelled and dried to a constant weight in an oven maintained at 105°C. The dried discs were weighed to obtain dry weight.
b) For shoots smaller than 4 cm dbh and branchwood and tops, the samples were weighed fresh and then oven dried and weighed following the same procedure as for the discs.
c) The wedges taken in a. above were weighed fresh (excluding bark), soaked in water for a minimum of 1 hour, then allowed to drain for 10 minutes. Surplus moisture was removed with a paper towel. The wedges were immersed in water to determine fresh volume by water displacement, then oven dried and weighed following the same procedure as for the discs.

Calculations

Volume

Volumes of sections were estimated using Huber's formula:

$$V = \frac{\pi \times D^2 \times L}{40\,000}$$

where V = Volume in m³
D = Mid diameter in cm
L = Length in m

Volume per hectare was estimated to 4 and 7 cm diameter over bark from the sample volumes using program SPLOT (Forestry Commission, 1976) in which a linear regression of volume of sample stems on basal area of sample stems is calculated. Volume for the plot is estimated by applying the regression to the diameter measurements, converted to basal area, of the remaining plot trees. In one of the plots this procedure was unnecessary as all trees had been sampled; in most others the sampling intensity was greater than 50%.

Weight

Weights per hectare were derived directly from sample measurements and estimated for the following components:

i. Stems less than 4 cm dbh
ii. Weight to 4 cm tdob and above
iii. Weight to 7 cm tdob and above
iv. Weight of tops and branches
v. Total above ground weight, i.e. sum of i, ii and iv.

Moisture content

Moisture content was estimated separately for the following components:

i. Shoots less than 4 cm dbh
ii. Stems 4-6.9 cm dbh
iii. Stems 7 cm dbh and above
iv. Tops and branches.

Moisture content was calculated as follows:

$$MC = \frac{W - w}{w} \times 100\%$$

where MC = moisture content in per cent
W = green weight in g
w = dry weight in g

Density

a. Green density for wedges sampled was calculated as:

$$GD = \frac{W}{V}$$

where GD = green density, g/cc
W = green weight in g
V = green volume in cc

b. Basic density for wedges sampled was calculated as:

$$BD = \frac{w}{V}$$

where BD = basic density, g/cc
w = dry weight in g
V = green volume in cc

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