WOODFUEL RESOURCE IN BRITAIN: APPENDICES

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Contractor

Forestry Contracting Association (FCA)
with Forestry Commission (FC)

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Part 2: APPENDICES

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WOODFUEL RESOURCE IN BRITAIN

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Appendices

9. APPENDICES

Appendix 1. Successful Bioenergy Capital Grant Scheme projects

Biomass heating and small scale CHP

- Econergy Ltd / Industrial Ecoheat Development Project
  Robert Rippengal
  69 Hampton Park
  Bristol
  BS6 6LQ
  Robert@econergy.ltd.uk
  12.4MWth
  The project will develop clusters of biomass heating installations across central and southern England. The project proposes to use Ala Talkkari Veto (40kWth - 480kWth output) and Compte Compact (320kWth - 4500kWth output) boilers. The fuel supply will initially be predominately from forestry woodfuel with dedicated energy crop resources developing over time.
  NOF Grant: £541,080.00

- Fermanagh Business Initiative / Biomass for Sustainable Development
  Eamonn Cox
  Fermanagh Business Initiative
  INTEC Centre
  36 East Bridge
  Street Enniskillen
  BT74 7BT
  Ecox@btclick.com
  The project proposes to establish a 'Flagship' sustainability showpiece based on an ESCO led wood heating cluster that can demonstrate wood fuel efficiency and economy. Boilers to be used will be supplied by Austrian company Polyteknik. In addition to alleviating fuel poverty the project will establish new opportunities for farmers through the development of energy crops, rejuvenating the local economy. It is hoped the project will form the basis upon which further projects can be developed, extending the benefits of wood heating.
  NOF Grant: £105,520.00

- Rural Energy Ltd / Rural Energy East Midlands Wood Heating Network
  Paul Evans
  Brook House
  25 Church Street
  Scalford
  Leic LE15 8DH
  PSEVANS1@ aol.com
  27MWth
  The project will simultaneously create an integrated production and supply network for wood fuel and a large cluster of small scale heating systems. It will supply an affordable renewable energy source to some 800 locations, including schools, increase rural jobs and utilise redundant farm buildings and under utilised farm staff and machinery. The project proposes to use Ala Talkkari Veto (40kWth - 480kWth output) and Compte Compact (320kWth - 4500kWth output) boilers. The new wood fuel market will

significantly improve wildlife habitat in the region by introducing low input energy crops and sound management of existing woodland.
NOF Grant: £879,060.00

- Torren Energy Ltd / Torren Energy Scottish Biomass Heat Clusters
  Steve Lamb
  Torren
  Glencoe
  Argyll
  PH49 4HX
  info@torrenenergy.co.uk
  (Split project - also funded under Priority Area 3B.)
  The project will extend on nearly 2 years of provision of biomass heating in Scotland. The project proposes to install boilers at a range of site though Ala Talkkari Boilers are currently used. The specification and efficiency of each boiler will differ according to the particular customer; however, all equipment installed will meet EN 303-5 energy efficiency criteria. Fuel will be a mixture of woodchip and forestry waste.
  NOF Grant: £580,655.00

- Wood Energy Ltd
  Keith McKendrick
  Pinkworthy Barn
  Oakford
  Tiverton
  Devon
  EX16 9EU
  keith@woodenergyltd.co.uk
  10MWth
  The project is to develop 7 separate clusters of automatic biomass heating systems within South West England (predominately Devon and Somerset) and Lincolnshire giving a total of 50 new installations over 3 years. The project proposes only to install biomass boilers conforming to EN 303-5 (over 86% energy efficiency). Fuel will be a mixture of energy crops and forestry brash. There will be a broad range of public, private and industrial sites ranging from 50kWth to 500kWth with a total installed capacity of 10,000kWth. This will build on the 16 systems already installed by Wood Energy Ltd.
  NOF Grant: £500,000.00

- Woodland Education Trust / Lignatherm
  David Saunders
  Woodland Enterprise Centre
  Flimwell East Sussex
  TN5 7RP
  info@woodnet.org.uk
  7.5MWth
  The project aims to develop the use of wood energy from crops, forestry and other aboricultural by-products in the South East of England. Boilers to be installed will have combustion efficiency ratings around 80% (Class 2/3). The project hopes to roll-out stated output in first year, proposing to increase output by 13MW per year.
  NOF Grant: £372,750.00

- Countryside Properties plc / Cliveden Community
  Garry Tarvet Countryside House
  The Drive
  Brentwood

Essex
CM13 3AT
Garry.tarvet@cpplc.com
0.26MWe / 0.26-0.4MWth (rated thermal output dependent on fuel moisture) The project will provide a carbon-neutral energy supply for a commercial housing development by using bio-fuel CHP. The development will create 200 new homes. Fuel used will be 100% wood chip, with LPG for engine start up/shut down purposes. Bio-fuel CHP has been identified by the Proposer as the most appropriate means of providing both heat and electricity to home carefully designed to minimise energy needs (also making use of passive energy sources).
DTI Grant: £195,000.00

- Econergy Ltd / Industrial Ecoheat Development Project
  Robert Rippengal 69
  Hampton Park
  Bristol
  BS6 6LQ
  Robert@econergy.ltd.uk
  7.2MWth
  The project proposes to deploy at least 4 regional heating clusters in industrial units across England. Ala Talkkari (40- 480kWth) and Compte Compact (320-4500kW) biomass boilers will be install, which have energy efficiencies over 80%. Phased commissioning over period of 6 years. Fuel will be forestry woodfuel initially with dedicated energy crop resources developing over time.
  DTI Grant: £335,940.00

- Nottinghamshire County Council / Nottingham Woodheat Project
  Peter Strutton
  Environment Dept
  NCC
  Trent Bridge
  House Fox Road West
  Bridgford
  Notts
  NG2 6BJ
  Peter.strutton@nottscc.gov.uk
  4MWth
  The project proposes to establish at least 6 heating installations across the county. Project has specified Talbott C1 - C10 range boilers as preferred choice, with output rating of 50-3000kWth. Talbott boilers are produced in the UK. Fuel will be a mix of wood crops and clean 'surplus' wood. Fuel supply identified to be in excess of 20,000 tonnes p/a Additional benefits identified in the project include a stimulus to the rural economy, encourage woodland husbandry and reduce landfill.
  DTI Grant: £197,600

- Torren Energy Ltd / Torren Energy Scottish Biomass Heat Clusters
  Steve Lamb
  Torren
  Glencoe
  Argyll
  PH49 4HX
  info@torrenenergy.co.uk
  (Split project - also funded under Priority Area 3B.)
  The project will extend on nearly 2 years of provision of biomass heating in Scotland.

The project proposes to install boilers at a range of site though Ala Talkkari Boilers are currently used. The specification and efficiency of each boiler will differ according to the particular customer; however, all equipment installed will meet EN 303-5 energy efficiency criteria. Fuel will be a mixture of woodchip and forestry waste.
DTI Grant: £193,552.00

Large/medium scale electricity and CHP

- Energy Power Resources Scotland Limited (EPRL) -£5m grant to help with the construction of a wood-fired combined heat and power (CHP) generator for Fort William paper manufacturer, Arjo Wiggins. The CHP generator at Arjo Wiggins will replace the existing 40-year-old oil fired generator. In addition to supplying the factory's entire heating requirements it will also contribute up to 80% of their electricity needs with the remaining spare capacity going into the national grid.

- Peninsula Power in Winkleigh, Devon - £11.5m to develop a 23MW biomass facility fuelled by locally grown energy crops.
  Mark Joslin
  Tresco House
  Leigh Road
  Chulmleigh
  Devon
  EX18 7BL
  Tel: 01769 581518
  Fax: 0870 0515922
  Email: ppl@greenidp.com

- Roves Energy in Sevenhampton, Wiltshire - £0.96m to build a 2.5Mwe and 5MWth combined heat and power plant (CHP) fuelled by up to 5000 hectares of locally grown energy crops
  Roves Energy:
  Rupert Burr
  Roves Farm
  Sevenhampton
  Nr Highworth
  Swindon
  Wiltshire
  SN6 7QG
  Tel: 01793 763939
  Fax: Not Listed
  Email: jb@rovesfarm.freeserve.co.uk

- Charlton Energy Ltd in Frome, Somerset - £2m to build a 7Mwe and7MWth CHP plant fuelled by forestry wood fuel and energy crops from lcal farmers and foresters
  Charlton Energy Ltd:
  Peter Charlton
  The Sawmills
  Buckland Down
  Frome
  Somerset
  BA11 2RH
  Tel: 01373 812501
  Fax: 01373 814842
  Email: peter@charltons.net

- Bronzeoak in Castle Cary, Somerset - £3.8m build a 7MWe and 1.5MWth CHP plant to fuel a wood products facility with electricity and heat as well as supplying heat for curing feedstock
  Bronzeoak:
  Dr Alastair Tod
  Bronzeoak House
  Stafford Road
  Caterham
  Surrey
  CR3 6JG
  Tel: 01883 332608
  Fax: 01883 347523
  Email: alastair.tod@bronzeoak.com

- Eccleshall Biomass in Eccleshall, Staffordshire - £0.5m to build a 2.2Mwe power station fuelled by locally grown energy crop – 'elephant grass' (miscanthus)
  Eccleshall Biomass:
  Amanda Grey
  Eccleshall Biomass Ltd
  Raleigh Hall
  Eccleshall
  Stafford
  ST21 6JL
  Tel: 01785 851190
  Fax: 01785 851190
  Email: raleighhall@farmersweekly.net

- Balcas Limited of Fermanagh, Northern Ireland - £2m CHP. The funding from the DTI's Bioenergy Capital Grants Scheme will help timber company Balcas Limited with the construction of a wood-fired combined heat and power (CHP) generator for their sawmill near Enniskillen. The new plant will use surplus sawdust and woodchips from the business to supply nearly all Balcas' electricity needs, saving the company up to £1m per year in electricity costs. The heat from the new plant will be used to produce refined wood pellets - a clean fossil fuel alternative - that will generate enough heat to keep 10,000 homes warm throughout the year.
  Brian Murphy
  Balcas Ltd
  Laragh
  Ballycassidy
  Enniskillen
  County Fermanagh
  BT94 2FQ

  Tel: 02866 323003
  Fax: 02866 323727
  Email: Brian.Murphy@balcas.com

Appendix 2. Principal users and producers

Details of sawmills with annual throughput of >5000m^3 timber with locational code (see Figure A1a)

Sawmill	Telephone
Solely or mainly softwood	
1 J.D.G. Munro & Partners - Dingwall Sawmills, Old Evanton Road, Dingwall, Ross-shire IV15 9RB	01349 863226
2 John Gordon & Son Ltd - Balblair Road, Nairn IV12 5LT	01667 453223
3 James Jones & Sons Ltd - Mosstodloch HQ: Broomage Avenue, Larbert, Stirlingshire FK5 4NQ	01324 562241
4 James Jones & Sons Ltd - KinnoirHQ: Broomage Avenue, Larbert, Stirlingshire FK5 4NQ	01324 562241
5 BSW Timber Plc - Boat of Garten HQ: East End, Earlston, Berwickshire TD4 6JA	01896 849255
6 BSW Timber Plc - Kilmallie HQ: East End, Earlston, Berwickshire TD4 6JA	01896 849255
7 James Jones & Sons Ltd - Aboyne HQ: Broomage Avenue, Larbert, Stirlingshire FK5 4NQ	01324 562241
8 James Cordiner & Son Ltd - Silverbank Sawmills, Banchory, Kincardineshire AB31 5PY	01330 823366
9 James Jones & Sons Ltd - Kirriemuir HQ: Broomage Avenue, Larbert, Stirlingshire FK5 4NQ	01324 562241
10 Riding Sawmills Ltd - Clyde Sawmills, Cardross, Dumbarton G82 5NP	01389 841263
11 James Callander & Son Ltd - Abbotshaugh Sawmills, Bainsford, Falkirk FK2 7XU	01324 621563
12 Windymains Sawmill - Windymains, Humble, East Lothian EH36 5PA	01875 8336102
13 A & J. Scott Ltd - Station Sawmills, Wooperton, Alnwick, Northumberland NE66 4XW	01668 217288
14 Adam Wilson & Sons Ltd - Heathfield Road, Ayr KA8 9SS	01292 267842
15 Robert Howie & Sons - Kenmuir Sawmills, Dalbeattie, Kirkcudbrightshire DG5 4PL	01556 610876
16 James Jones & Sons Ltd - Dumfries HQ: Broomage Avenue, Larbert,	01324 562241
17 BSW Timber plc - Carlisle HQ: East End, Earlston, Berwickshire TD4	01896 849255
18 Taylormade Timber Products Ltd - Sherburn Hill, Durham, DH6 1 PS	01913 720524
19 Conwy Timber Company - Gwyddelwern Sawmills, Gwyddelwern, Denbighshire LL21 9DG	01490 412241
20 Conwy Timber Company - Morfa Sawmills, Conwy, N Wales LL32 8HB	01492 596601
21 ETC Sawmills Ltd - Elson, Ellesmere, Shropshire SY12 9JW	01691 622441
22 Kronospan Sawmilling Ltd - Chirk, Wrexham LL14 5NT	01691 775256
23 Jeffrey Walker & Co Ltd - Brunel Ind Estate, Harworth, Doncaster, South Yorkshire DN1 1 8QA	01302 751175
24 Charles Ransford & Sons Ltd - Station Street, Bishop's Castle, Shropshire SY9 5AQ	01588 638331
25 BSW Timber plc - Newbridge on Wye, HQ: East End, Earlston, Berwickshire TD4 6JA	01896 849255
26 M R Ellis (Timber) Ltd - Hevingham, Norwich	01603 755321
27 Pontrilas Timber & Builders Merchants Ltd - Pontrilas, Nr Hereford, Herefordshire HR2 OBE	01981 240444

28 Forest Fencing Ltd - Stanford Court, Stanford Bridge, Worcester WR6 6SR 01886 812451
29 BSW Timber plc - Senghenydd HQ: East End, Earlston, Berwickshire TD4 6JA 01896 849255
30 Barite Sawmills Ltd - Lakeside Sawmills, Broadway Lane, South Cerney, 01285 860781
31 Stuart H Somerscales Ltd - Keelby, Grimsby DN41 8HU 01469 560704
32 Jeffrey Walker & Co Ltd - Doncaster Road, Nottingham DN11 8QA 01909 732619
33 R F Giddings & Co Ltd - Ringwood Road Sawmills, Bartley, Southampton, S040 7LT 01703 813157
34 Kerr Timber Products Ltd - Annan, Dumfriesshire, DG1 2 6SL 01461 201622
35 Tulloch Timber (Nairn) Ltd - Grigorhill Industrial Estate, Nairn IV12 5HY
36 Gwent Timber Products Ltd - Crumlin, Newport, Gwent NP1 4AG 01495 248080
37 James Kingan & Sons Ltd - New Abbey, Dumfries DG2 8BY 01387 850282
38 Perthshire Timber Co - Polney Sawmill, Dunkeld, Perthshire PH8 OHU 01350 727494
39 P Irving & Sons - Hutton Roof Sawmills, Kirkby Lonsdale, Carnforth LA6 2PE 01524 271510

Mills not identified on map
54 Boughton Sawmills, Maun Way, Newark, Notts, NG229ZD 01623 861379
86 Anglian Timber Ltd, Chirnside, Nr Duns, Berwickshire TD11 3XJ 01890 818213
114 Pallet Logistics Ltd, Fordoun, Laurencekirk, Kincardineshire,AB30 1JR 01561 320469
139 G&T Evans, Dulas Mill, Ffordd Mochdre, Newtown, Powys, SY16 4JD 01686 622100
315 Cally Sawmill Ltd, Blairgowrie Road, Dunkeld, PH8 0HU 01350 727 305
500 Anglian Timber Ltd, North Trade Road, Battle, East Sussex TN33 9LJ 01424 775333

Solely or mainly hardwoods
1 BSW Timber PLC – Petersmuir, HQ: East End, Earlston, Berwickshire TD4 6JA 01896 849255
2 Duffield Timber - Green Lane, Melmerby, Ripon, North Yorkshire HG 5JB 01765 640564
3 John Boddy (Timber) Ltd - Riverside Sawmills, Boroughbridge, North Yorkshire YO51 9LJ 01423 322370
4 Barchards Ltd - Gibson Lane, Melton, North Ferriby, East Yorkshire HU14 3HF 01482 633388
5 Nidd Valley Sawmills Ltd - Dacre Banks, Harrogate, North Yorkshire HG3 4EA 01423 780220
6 Stuart H Somerscales Ltd - Keelby, Grimsby DN41 8HU 01909 732619
7 Henry Venables Ltd - Doxey Road, Stafford, Staffordshire ST16 2EN 01785 259131
8 Whitmores' Timber Co Ltd - Main Road, Claybrooke Magna, Lutterworth, Leics LE17 5AQ 01455 209121
9 Vastern Timber Co Ltd - The Sawmills, Wootton Bassett, Swindon, Wilts SN4 7PD 01793 853281
10 Pontrilas Timber & Builders Merchants Ltd - Pontrilas, Nr Hereford, Herefordshire HR2 OBE 01981 240444
11 B & K Earle - Woodcote Sawmill, Reading 01491 680520
12 East Bros (Timber) Ltd - West Dean, Salisbury, Wiltshire SP5 1 JA 01794 340270
13 A J Charlton & Sons Ltd - Buckland Down, Frome, Somerset BA11 2RH 01373 812501
14 W L West & Sons Ltd - Selham, Petworth, West Sussex GU28 OPJ 01798 861611
15 Morgan & Co (Strood) Ltd - Knight Road, Rochester, Kent ME2 2BA 01634 290909

Mills not identified on map
552 T&G Norman, Shed 25, Francismoor Wood, Brampton Road, Longtown Carlisle, Cumbria CA6 5TR 01228 791 777

Figure A1a. Principal sawmills in Britain. Blue represents the main softwood mills and red represents the main hardwood mills.

Details of panel board and paper mills.

Company	Town	Postcode	Telephone	X	Y
1 Nexfor Ltd	Inverness	IV2 7JQ	01463 792424	275048	849174
2 Nexfor Ltd	Cowie	FK7 7BQ	01786 812921	283708	688834
3 Caledonian Paper Plc	Irvine	KA11 5AT	01294 312020	233708	634940
4 Egger Barony Ltd	Auchinleck	KA18 2LL	01290 426026	254723	621870
5 Egger UK Ltd	Hexham	NE46 4JS	01434 602191	394613	564691
6 Iggesund Paperboard Ltd	Workington	CA14 1JX	01900 601000	300420	531211
7 U P M Kymene UK Ltd	Shotton	CH5 2LL	01244 280000	330415	371610
8 Kronospan Ltd	Chirk	LL14 5NT	01691 773361	328727	338242
9 St. Regis Paper Co Ltd	Caldicot	NP26 5XT	01291 420751	350168	187508
11 Nexfor Ltd	South Molton	EX36 4HP	01769 572991	269896	125902

Figure A1b. Principal paper, pulp and panel mills in Britain

Contacts for representative organisations

Forest and Timber Association
Tel: 0131 538 7111
Fax: 0131 538 7222
E-mail: info@forestryandtimber.org

UK Forest Products Association
Tel: 01786 449029
Fax: 01786 473112
e-mail: dsulman@ukfpa.co.uk

Contacts for Forestry Commission Harvesting and Marketing Officers:

England:	Alan Corson Tel: 01904 696300 Fax: 01904 696310 E-mail: alan.corson@forestry.gsi.gov.uk
North Scotland	Les Bryson Tel: 01463 252603 Fax: 01476 243846 E-mail: les.bryson@forestry.gsi.gov.uk
South Scotland	Mike Green Tel: 01387 272440 Fax: 01387 251491 E-mail: mike.green@forestry.gsi.gov.uk
Wales	Hugh Jones Tel: 01970 821211 Fax: 01970 828151 E-mail: hugh.jones@forestry.gsi.gov.uk

Appendix 3. Development of allometric relationships for principal tree components in British forest stands

This appendix details the research underpinning the allometric equations used for predicting the biomass of different components of trees in Britain. Crown biomass functions were calibrated for 17 species of conifers and broadleaves. Root biomass functions were calibrated for 6 species of conifers and can be approximately applied to a further 6 species for which data was available.

Data preparation

The data was compiled from a number of sources identified by Forest Research Mensuration Branch. The bulk of the data for conifers came from the Forest Research 'treepull' data set. Additional Sitka spruce data was obtained from Burger (1953), Carey and O'Brien(1979), Bormann (1990) and Bergez (1988). A sequence of papers by Burger also provided data for other conifer and broadleaf species (Burger, 1935 to 1953). Additional data on broadleaf trees was obtained from Bunce (1968). The summary of crown biomass data sources is given in Table A3.1.

The initial objective was to produce a consistent data set with a breakdown of above ground biomass components and, where present, root biomass. The original data sets were incomplete and a certain amount of data manipulation was necessary in order to provide the full data set; the data are summarised by author below.

1. Burger

No root biomass information was available. Stem biomass was estimated from stem volume functions and the known nominal specific gravity for the different species

2. Bunce

No root biomass information was available. Stem biomass was estimated as for Burger, and branch mass was calculated as the difference between above-ground woody biomass and stem biomass.

3. Carey and O'Brien

All information was available.

4. Bormann

No root biomass information was available. Stem biomass and branch mass were calculated as for Bunce. Following a discussion with Mensuration Branch experts, an assumption was made that the estimates of above-ground biomass referred to woody biomass only.

5. Bergez

No root biomass information was available. Stem biomass and branch biomass were estimated as for Bunce.

6. Forest Research (treepull data set)

The data set contained fresh weights. The dry weight of the stem was calculated by multiplying the stem volumes provided in the data set by species nominal specific gravity for wood of the relevant tree species (Lavers and Moore, 1983). The dry matter content of the stem was then calculated by dividing the dry stem weight by the fresh stem weight. The estimated dry matter content was assumed also to apply to the roots. In order to estimate the dry matter content of the crown, an adjustment was necessary. This adjustment was based on an analysis of summary data presented in Rollinson and Evans (1987).

The treepull data set only provided assessments of crown biomass – i.e. for woody branches and foliage combined. In order to permit conversion between estimates of crown biomass and woody branch biomas, two sets of functions were calibrated to predict tree foliage mass from branch mass or from crown mass. These were calibrated using detailed data from Burger's papers. It was possible to determine two distinct species groupings. Accordingly, one set of functions was calibrated based on data for Douglas fir, Norway spruce, Sitka spruce and silver fir, while another was calibrated based on data for European larch, oak and beech. The functions were then applied to appropriate tree species as indicated in Table A3.1. Note that it was assumed that estimation of foliage mass for pines could be carried out using the 'spruces and firs model' due to a complete lack of data for this species group.

Where trees contained no estimates of aboveground biomass, crown biomass, or aboveground woody biomass, they were excluded from the data set.

All data were quality-assessed by careful examination of a number of scatter plots of the variables of interest.

Table A3.1 Summary of crown biomass data sources by species

Species	**Source**					
	Bunce	**Burger**	**Carey**	**Bormann**	**Bergez**	**FC (treepull)**
Scots pine *						★
Corsican pine *						★
Lodgepole pine *						★
European larch **		★				★
Japanese larch **						★
Douglas fir *		★				★
Norway spruce *		★				★
Sitka spruce *		★	★	★	★	★
Grand fir *						★
Noble fir *						★
Silver fir *		★				
Western hemlock *						★
Red cedar *						★
Oak **	★	★				
Beech **		★				
Ash **	★					
Birch **	★					
Red alder **						★
Sycamore **	★					

*   ; Uses 'spruces and firs' leaf mass function
**   ; Uses 'broadleaf' leaf mass function

Development of allometric equations

Calibration procedure

All of the volume and biomass functions were calibrated using least-squares regression methods. All of the models for biomass calibration involved tree dbh, tree total height or a combination of the two. For the root biomass functions, root depth was used in conjunction with site information in order to investigate site effects. Separate models for crown biomass were fitted for trees with dbh <7 cm and for trees with dbh 7 cm or greater. This is because, by convention, data for trees falling into the former group will include stem wood as part of the crown biomass, while the latter group will not. This is likely to cause a discontinuity in the relationships between tree crown or branch biomass and dbh at around the 7 cm point. Weighted regression methods were used to correct for heterogeneity of residual variance in all crown and root biomass models.

Species differences were examined by careful consideration of graphs of the relationships between the primary variables (dbh, height and biomass), and by species-coded residual plots. Decisions on species groupings were made by reference to these graphs as the work progressed.

The final decision on the choice of model was based on a number of criteria. Adjusted R^2 statistics were used to eliminate poorly fitting models. The remaining models were assessed by examination of residuals, their stability and their biological meaning. Due to the discontinuity at 7cm dbh for the crown biomass models, the ">7cm dbh" models were allowed to contain constants should the R^2 statistic indicate an improvement. The use of stump diameter (calculated as a function of dbh) did not generally indicate an improvement over the use of dbh and did not allow the removal of the constants. The models considered during initial calibration are listed in Table A3.2. In addition to these models, the powers attached to height and diameter were fixed when appropriate and common power terms were considered.

Root Biomass Calibration

There were only six species for which the root biomass data was available over a wide enough range of dbh for confident calibration to be achieved. These six models were calibrated and other species for which data were available were allocated to the closest available model. Site conditions are known to influence the composition of the root structure. A preliminary graphical investigation of the effect of root depth was undertaken but no consistent patterns emerged. Accurate models will almost certainly need to take into account soil types, drainage and silviculture, but such analysis was outside the scope of this project. The objective here was to provide the best possible estimates based on the data available so the root biomass equations should be applied with appropriate caution.

Table A3.2. List of candidate models included in calibration exercise

1. $\beta.DBH^{p}$
2. $\alpha + \beta.DBH^{p}$
3. $\beta.DST^{p}$
4. $\alpha + \beta.DST^{p}$
5. $\beta.DBH^{2}$
6. $\alpha + \beta.DBH^{2}$
7. $\beta.DST^{2}$
8. $\alpha + \beta.DST^{2}$
9. $\beta.DBH^{p}.Totht^{q}$
10. $\alpha + \beta.DBH^{p}.Totht^{q}$
11. $\beta.DST^{p}.Totht^{q}$
12. $\alpha + \beta.DST^{p}.Totht^{q}$
13. $\beta.DBH^{2}.Totht^{q}$
14. $\alpha + \beta.DBH^{2}.Totht^{q}$
15. $\beta.DST^{2}.Totht^{q}$
16. $\alpha + \beta.DST^{2}.Totht^{q}$
17. $\beta.Totht^{q}$
18. $\alpha + \beta.Totht^{q}$
19. $\beta.DBH^{r} + \gamma.DBH^{p}.Totht^{q}$
20. $\alpha + \beta.DBH^{r} + \gamma.DBH^{p}.Totht^{q}$
21. $\beta.DST^{r} + \gamma.DST^{p}.Totht^{q}$
22. $\alpha + \beta.DST^{r} + \gamma.DST^{p}.Totht^{q}$
19. $\beta.DBH^{2} + \gamma.DBH^{p}.Totht^{q}$
20. $\alpha + \beta.DBH^{2} + \gamma.DBH^{p}.Totht^{q}$
21. $\beta.DST^{2} + \gamma.DST^{p}.Totht^{q}$
22. $\alpha + \beta.DST^{2} + \gamma.DST^{p}.Totht^{q}$
23. $\beta.DBH + \gamma.DBH^{p}$
24. $\alpha + \beta.DBH + \gamma.DBH^{p}$
25. $\beta.DST + \gamma.DST^{p}$
26. $\alpha + \beta.DST + \gamma.DST^{p}$

Key to variables:
DBH = Diameter at breast height.
DST = Diameter at stump height.
Totht = Total height.

Crown Biomass Calibration

Previous work into estimation of crown biomass equations had involved the use of mathematical splines to account for effects due to the change in measurement of the tree crown and stem as the tree grows, notably around the 7 cm dbh point. For this exercise any change at 7 cm dbh was accounted for by using discontinuous functions (i.e a piecewise approach) rather than splines.

Of the broadleaf species, only oak appeared in more than one data set (Bunce, 1968; Burger 1947). Large differences were indicated in the relationships between the primary variables for these two data sets. This was believed to reflect fundamental difference in the stand types considered by Bunce and Burger. Bunce was reporting assessments made in semi-natural woodlands including coppice with standards in Britain, while Burger was reporting results for managed high forest in Switzerland. A decision was therefore taken to carry out separate calibration exercise for data originating from 'high forest' and 'non-high forest' stands. The latter functions were assumed to be more representatives of trees growing in British stands and were applied in this study.

Results

Details of the allometric equations finally selected and of associated parameter estimates are provided in Tables A3.3 (leaf biomass), A3.4 (crown biomass) and A3.5 (root biomass). Estimates of woody branch biomass may be computed as the difference between crown biomass and leaf biomass.

Table A3.3 Summary of leaf biomass models and parameter estimates

Broadleaf and larch	Needle mass = 0.05685480 - 0.05685480*($0.10557281^{drybranch}$)
	Needle mass = 0.06391085 - 0.06391085*($0.17108421^{drycrown}$)
Spruces and firs	Needle mass = 0.19823116 - 0.19823116*($0.10566005^{drybranch}$)
	Needle mass = 0.22264859 - 0.22264859*($0.23934263^{drycrown}$)

Table A3.4 Summary of crown biomass models and parameter estimates

Species	**Function (<=7cm dbh)**	**Parameters (<=7cm dbh)**	**Function (>7cm dbh)**	**Parameters (>7cm dbh)**
spruces and firs (NS,SS,GF,NF, SF)	$\gamma.DBH^p$	p=1.45904650 γ=0.00052193	$\alpha + \gamma.DBH^p$	α=0.00607220 p=2.55784701 γ=0.00000958
Douglas fir (DF)	NO DATA		$\gamma.DBH^p.Totht^q$	p=2.71692894 q=-1.26059545 γ=0.00034610
High-Forest Beech (BE)	$\gamma.DBH^2$	γ=0.00025950	$\alpha + \gamma.DBH^p$	α=0.00685783 p=2.46575735 γ=0.00001920
High-Forest Oak (OK)	$\gamma.DBH^2$	γ=0.00021612	$\gamma.DBH^p.Totht^q$	p=2.35009373 q=-1.02161521 γ=0.00054224
Non High-Forest (OK,AH,BI,SY, RA)	$\gamma.DBH^p.Totht^q$	p=2.06704428 q=0.73218540 γ=0.00005122	$\alpha + \gamma.DBH^p.Totht^q$	α=0.00729453 p=3.67047187 q=-1.44028024 γ=0.00003081
Corsican pine (CP)	NO DATA		$\gamma.DBH^p$	p=1.72105599 γ=0.00013997
Scots and Lodgepole pine (SP,LP)	NO DATA		$\alpha + \gamma.DBH^p$	α=0.00435122 p=2.51380074 γ=0.00001321
larch (EL,JL)	NO DATA		$\alpha + \gamma.DBH^p$	α=0.00564017 p=2.10576258 γ=0.00003041

Table A3.5 Summary of root biomass models and parameter estimates

Species Calibrated	Allocated Species	Function	Parameters
Sitka spruce (SS)	SS, RA	$\gamma.DBH^p$	p=2.68358135 γ=0.00001115
Lodgepole pine (LP)	LP, JL	$\gamma.DBH^p$	p=2.42909375 γ=0.00002242
Douglas fir (DF)	DF, WH	$\gamma.DBH^p$	p=2.42093716 γ=0.00002179
Scots pine (SP)	SP, GF	$\gamma.DBH^p$	p=2.10019503 γ=0.00005595
Corsican pine (CP)	CP, NF, RC	$\gamma.DBH^p$	p=2.39136175 γ=0.00001537
Norway spruce (NS)	NS	$\gamma.DBH^p$	p=2.49196588 γ=0.00001204

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Appendix 4. Development of models of tree size distributions

This appendix describes the approach used in the development of models for estimating the distribution of different tree sizes (in terms of dbh and height) in a stand of trees based on stand-scale mensurational variables available as outputs from models used in production forecasting (e.g. mean dbh, top height, numbers of trees and volume per hectare).

The models were developed in two stages. First, models were constructed for estimating the distribution of numbers of trees and volume per hectare for 1 cm dbh classes in a stand. In the second stage, a procedure was defined for estimating the mean height of trees for 1 cm dbh classes in a stand.

Models of distribution of numbers of trees and volume per hectare

These models were based on estimates from previous analyses, published as the so-called 'stand' and 'stock' tables in general use in the British forest industry (Christie, 1983; Edwards and Christie, 1981; Hamilton, 1998). The stand tables provide estimates of the percentage of the total numbers of trees per hectare falling into different 1 cm dbh classes within a stand of trees. Christie (1983) demonstrated that the main factors determining this distribution at a given point in the life cycle of a stand of trees grown in Britain were:

- Stand mean dbh at the stand age of interest
- The silvicultural prescription being applied to the stand, defined in terms of three broad classes.

Having accessed the appropriate stand table, the percentage estimates for different 1 cm dbh classes can be combined with an estimate of the total number of trees per hectare to obtain estimates of numbers of trees in each dbh class.

The stock tables are identical in format to the stand tables except that they provide estimates of the percentage of the total stem volume per hectare falling into different 1 cm dbh classes within a stand of trees. Thus, having accessed the appropriate stock table by reference to stand mean dbh and identifying broad class of silvicultural prescription, the percentage estimates for different 1 cm dbh classes can be combined with an estimate of the total volume per hectare to obtain estimates of stem volume in each dbh class.

For the purposes of this project, the published stand and stock tables were limited because estimates were only available for a limited range of values of stand mean dbh that was not adequate to represent all stand types encountered in the British forest estate. In order to permit continuous interpolation and extrapolation of the tables for values of mean dbh not represented, mathematical functions were fitted to the published tables using the method of maximum likelihood.

Stand tables

The probability density function describing the stand tables can be described using an incomplete beta distribution with the following form:

$$p(dbh) = \frac{1}{\beta} x^{P-1}(1-x)^{Q-1} \qquad ; dbh \geq 4cm$$

$$P(dbh) = 0 \qquad ; dbh < 4cm$$

where

$$x = \frac{dbh^2 - dbh_{min}^2}{dbh_{max}^2 - dbh_{min}^2}$$

$$\beta = \int_{D^2}^{dbh_{max}^2} x^{P-1}(1-x)^{Q-1} \cdot dx$$

$$D = \max(4, dbh_{min})$$

and dbh_{min} and dbh_{max} are given by the equations in Table A4.1. The value of β as given by the equations indicated above must be found by numerical integration. The value of parameter P depends on stand mean dbh and silvicultural prescription, with three broad regimes being defined. The three silvicultural regimes are defined in Algorithm A4.1. Equations for estimation of parameter P are given in Table A4.2.

Table A4.1. Equations for minimum and maximum dbh

General form of equation:

$$dbh_{min} = \max(0, A + Bdbh_m)$$

$$dbh_{max} = 1 + (C + Ddbh_m)$$

where dbh_m = C + D dbh_m

Parameter	Regime		
	1	2	3
A	-1.913	-1.815	-1.481
B	0.56654	0.65401	0.75505
C	0.369	1.577	1.463
D	1.73205	1.41899	1.25854

Algorithm A4.1. Definition of silvicultural regimes for access to stand and stock tables

```
IF (PLANTING_SPACING > 3.0) THEN
        REGIME = 3
ELSE
        Y = 1.5 – 0.1454863345 * (PLANTING_SPACING ** 3.9693623)
        IF (THINNING_INTENSITY > Y) THEN
            IF (BEFORE_FIRST_THINNING_EVENT) THEN
                IF (SPACING  > 2.2) THEN
                    REGIME = 2
                ELSE
                    REGIME = 1
                END IF
            ELSE
                REGIME = 3
            END IF
        ELSE
            IF (PLANTING_SPACING > 2.2) THEN
                REGIME = 2
            ELSE
                Z = 0.5 – 0.227272727272727 * PLANTING_SPACING
                IF (THINNING_INTENSITY > Z) THEN
                    IF (BEFORE_FIRST_THINNING_EVENT) THEN
                        REGIME = 1
                    ELSE
                        REGIME = 2
                    END IF
                ELSE
                REGIME = 1
                END IF
        END IF
    END IF
END IF
```

Table A4.2 Estimation of parameter P for stand table functions

General form of equation:

$$P = \max\left[1.001, A + (B + Cdbh_m)R^{dbh_m}\right]$$

Parameter	Regime		
	1	2	3
A	0.689	0.756	-1.05
B	-3.36	-3.369	0.81
C	0.734	0.5942	0.2368
R	0.8817	0.91094	0.9676

Given parameter P, parameter Q needs to be set such that the quadratic mean of the incomplete probability density function as defined above is equal to the value of the stand quadratic mean dbh used as an input variable in the estimation of parameter P. In other words, parameter Q is selected so as to give,

$$\int_{D^2}^{dbh^2_{max}} xp(x) \cdot dx = \left(dbh^2_m\right)$$

where dbh_m = stand quadratic mean dbh. If $dbh_{min} \geq$ 4cm, parameter Q can be computed using the explicit formula,

$$Q = P\left(\frac{1}{F} - 1\right)$$

where $F = \frac{\left(dbh^2_m - dbh^2_{min}\right)}{\left(dbh^2_{max} - dbh^2_{min}\right)}$

Note that expressing the probability density function in terms of the square of dbh rarther than untransformed dbh is necessary to permit the application of the above equations. If dbh_{min} < 4 cm, the value of Q needs to be found iteratively. It is possible to provide an approximation to the optimal value of Q which may be used as a starting value for the iterative procedure. Functions for estimating this starting value are given in Table A4.3.

Table A4.3. Estimation of starting value for optimisation of parameter Q for stand table functions

General form of equation:

$$Q = \max\left[1.001, A + (B + Cdbh_m)R^{dbh_m}\right]$$

Parameter	Regime		
	1	2	3
A	2.28417	1.43191	-1.1081
B	-8.784	-4.9792	1.7039
C	2.02136	1.20112	0.340412
R	0.882806	0.908795	0.965223

Stock tables

The probability density function describing the stock tables can be described using an incomplete beta distribution with the following form:

$$p(dbh) = \frac{1}{\beta} x^{P-1}(1-x)^{Q-1} \qquad ; dbh \geq 7cm$$

$$P(dbh) = 0 \qquad ; dbh < 7cm$$

where

$$x = \frac{dbh^2 - dbh_{min}^2}{dbh_{max}^2 - dbh_{min}^2}$$

$$\beta = \int_{D^2}^{dbh_{max}^2} x^{P-1}(1-x)^{Q-1} \cdot dx$$

$$D = \max(7, dbh_{min})$$

and dbh_{min} and dbh_{max} are given by the equations in Table A4.1. The value of β as given by the equations indicated above must be found by numerical integration.

The values of parameters P and Q depend on stock mean dbh and silvicultural prescription, with three broad regimes being defined as already described in Algorithm A4.1. Equations for estimating parameter P are given in Table A4.4. If $dbh_m \leq k$ cm the value of parameter Q is estimated using equations as given in Table A4.5 and k is a cut-off value specified for each Table Code as in Table 4.5. If $dbh_{min} > k$ cm the value of parameter Q is found from the equation,

$$Q = P\left(\frac{1}{G} - 1\right)$$

Equations for estimating G are also given in Table A4.5.

Table A4.4. Estimation of parameter P for stock table functions

General form of equation:

$$P = \max\left[1.001, A + (B + Cdbh_m)R^{dbh_m}\right]$$

Parameter	Regime		
	1	2	3
A	1.0242	0.9467	-1.38
B	-32.9	-7.71	1.34
C	3.83	1.014	0.2598
R	0.8207	0.89952	0.9693

Table A4.5. Estimation of parameter Q for stock table distributions

General form of equation:

$$Q = \max\left[1.001, A + (B + C\,dbh_m)R^{dbh_m}\right] \quad ; dbh_m \le k$$

$$Q = P\left(\frac{1}{G} - 1\right) \quad ; dbh_m > k$$

where $G = \alpha + \beta\phi^{dbh_m}$

Parameter	Regime		
	1	2	3
A	1.9597	1.4179	-1.43
B	-50.89	-9.39	1.86
C	6.061	1.332	0.2841
R	0.81614	0.89687	0.96893
α	0.34323685	0.393672	0.4654352
β	1.6699	0.09378	-0.08758
Φ	0.855128	0.96678	0.91699
k	80.0	66.0	50.0

Models of total tree height for varying dbh classes in a stand

The estimation of average tree height for different dbh classes involved working out the average stem volume of a tree in each dbh class and then using this value and the known dbh to infer the most likely height of a tree of the given species.

The Forestry Commission has produced equations for estimating tree stem volume for the major tree species in Britain. These take the general form:

$$v = f\,(dbh, T)$$

where v and dbh are the stem volume and dbh of the tree respectively, T is the so-called “tariff number” of the tree (Hamilton, 1998) and f has a fairly simple linear form with standard, known parameter values (Edwards, 1998). This equation could be rearranged in a straightforward manner to express T in terms of v and dbh:

$$T = g\,(dbh, v)$$

where g is also takes a fairly simple linear form. Equations have been developed for the main conifer tree species in Britain that permit the estimation of T from tree dbh and total height (Christie, 1982; Hamilton, 1998). These equations also take the following simple form:

$$T = a + b\,dbh + c\,h$$

where h is the total height of the tree and a, b and c are species-specific parameters. A simple rearrangement of this equation permits tree height to be expressed in terms of tree dbh and stem volume:

$$h = (T - a - b\,dbh) / c.$$

Combining equations above gives an explicit, species-specific relationship for tree height in terms of tree dbh and volume:

$$h = (g\ (dbh, v) - a - b\ dbh) / c,$$

thus the above equations may be used to infer tree height for each of the dbh classes represented in the size class distribution model given an estimate of the average stem volume of a tree for the dbh class of interest and tree stem volume equation parameter estimates for the tree species of interest.

The models described in the previous section for estimating number of trees per hectare and volume per hectare in each 1 cm dbh class in a stand can be combined to provide estimates of the average stem volume of a tree for each dbh class. Quite simply, this involves dividing the estimate of volume per hectare for each dbh class by the equivalent estimate of number of trees per hectare.

The Forestry Commission has also produced equations expressing stem volume in terms of tree dbh and height for a range of broadleaf species but these equations make use of so-called tree ‘timber height’ rather than total height (Edwards, 1998; Hamilton, 1998). For the purposes of this project, new tree stem volume equations were developed for the most important broadleaf tree species expressed in terms of tree dbh and total height. Data from Forest Research permanent mensuration sample plots were used in the development and calibration of these models. The new models for broadleaf species took the form:

$$v = a + b\ dbh^2\ h^p$$

where a, b and p are species-specific model parameters (parameter estimates for key broadleaved species are given in Table A4.6). This equation can be rearranged to give h in terms of dbh and v thus:

$$h = [(v - a) / (b\ dbh^2)]^{1/p}$$

Table A4.6. Parameter values for single-tree stem volume equations for selected broadleaf tree species

Species	**Single tree volume function**
Beech	$v = -0.014306 + 0.0000748\ dbh^2\ h^{0.75}$
Ash	$v = -0.012107 + 0.0000777\ dbh^2\ h^{0.75}$
Birch	$v = -0.009184 + 0.0000673\ dbh^2\ h^{0.75}$
Oak	$v = -0.011724 + 0.0000765\ dbh^2\ h^{0.75}$
Sycamore	$v = -0.012668 + 0.0000737\ dbh^2\ h^{0.75}$
Poplar	$v = -0.004298 + 0.0000435\ dbh^2\ h^{0.89}$

In principle, this approach could now be used to assign estimates of tree height to each dbh class off interest for both conifer and broadleaf species. However, in practice there were problems in obtaining consistent estimates in all situations, in particular for dbh classes at the extreme ends of a given distribution. To avoid such anomalous results, a robust procedure was adopted that involved the following steps.

1. An estimate of stand mean height was calculated using the approach described above.
2. Stand dominant dbh was calculated from the dbh distribution model. (Dominant dbh is defined as the quadratic mean dbh of the 100 largest-dbh trees per hectare in the stand of interest. Trees with dbh equal to dominant dbh will have a an average height equal to stand top height.)
3. Steps 1 and 2, when combined with results from computer-based yield models for the time step of interest, could be regarded defining two points on a graph of average tree height (per dbh class) versus tree dbh, specifically (mean dbh, mean height) and (dominant dbh, top height). A third point on this graph could be defined on theoretical grounds, assuming that a tree of 1.3 m height must have a dbh of zero. These three points could be used to construct a power curve describing the relationship between average tree height (per dbh class) and tree dbh with the form $h = 1.3 + \beta\ dbh^{\gamma}$ (where the values of the parameters β and γ can be found by substituting the values for the tree points into the equation).

The algorithms used for the procedure outlined above are given below (algorithms A4.2 and A4.3). As detailed in these descriptions, certain constraints needed to be introduced to ensure robust estimation in certain extreme cases, for example involving low total numbers of trees per hectare or small mean dbh values. As an additional constraint, the procedure was carried out using inputs from computer based yield models for the stand at the time step of interest <u>before removal of any thinnings</u>. The resultant height-dbh curve was then assumed also to apply to the main stand after removal of any thinnings and also to any thinnings or mortality.

Algorithm A4.2. Construction of height – dbh relationship for stand

```
Obtain total number of trees per hectare and top height from computer-based models

Estimate tree dbh distribution using models defined earlier.

IF (Total number of trees per hectare in stand <= 200) THEN

        Height of all dbh classes = stand top height (taken directly from computer-based yield model)

ELSE

                Estimate stand mean height and dominant using Algorithm A4.3

                IF ((mean height / top height) > 0.95) THEN

                        Height of all dbh classes = top height

                ELSE

                        Estimate height of dbh classes assuming a curve of the form
                        h = 1.3 + β dbh^γ

                END IF

END IF
```

Algorithm A4.3. Estimation of stand mean height and dominant dbh

IF (Stand Mean DBH is less than 10 cm) THEN

Assume P = 0.4

(Note, the value of 0.4 is based on analyses of sample plot data.)

Calculate an estimate Y as the product of P and the value of Stand Top Height (as obtained directly from computer-based yield models)

Estimated Stand Mean Height = max (Y, Stand Top Height – 2.5)

(Note The assumed maximum difference between mean height and top height of 2.5 metres is based on analyses of sample plot data.)

Use the "stand table" distribution and the number of trees per hectare to find the stand dominant dbh, d2.

ELSE

Use the "stand table" distribution to find the number of trees per hectare N1 in the 3 dbh classes equal to and 1 cm either side of the stand mean dbh, d1.

Use the "stock table" distribution to find the volume per hectare V1 in the 3 dbh classes equal to and 1 cm either side of the stand mean dbh.

Estimate mean volume equivalent to mean dbh v1 as V1 / N1

Use the appropriate volume function for the species to "reverse-estimate" the value of mean height h1 from v1 and stand mean dbh, d1.

Use the "stand table" distribution and the number of trees per hectare to find the stand dominant dbh, d2.

Use the "stand table" distribution to find the number of trees per hectare N2 in the 3 dbh classes equal to and 1 cm either side of the stand dominant dbh.

Use the "stock table" distribution to find the volume per hectare V2 in the 3 dbh classes equal to and 1 cm either side of the stand dominant dbh.

Estimate mean volume equivalent to mean dbh v2 as V1 / N1

Use the appropriate volume function for the species to "reverse-estimate" a value of top height h2 from v2 and stand dominant dbh d2.

(N.B. This estimate of top height should NOT be used to replace the value obtained directly from the computer-based yield models and used elsewhere in this algorithm.)

Estimate P as h1/h2

Calculate an estimate Y as the product of P and the value of Stand Top Height (taken directly from computer-based yield models).

Z = max (Y, Stand Top Height – 2.5)

(Note The assumed maximum difference between mean height and top height of 2.5 metres is based on analyses of sample plot data.)

Estimated Stand Mean Height = min (Z, Stand Top Height – 0.1)

(Note, assuming a minimum difference between mean height and top height of 0.1 m is probably more robust than assuming a maximimum value of P of e.g. 0.95.)

END IF

END OF ALGORITHM

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Appendix 5. Data and parameters in BSORT model.

This appendix contains tables of basic data and parameter estimates used to calibrate the BSORT model for estimation of biomass in different components of trees and forest stands of different species.

Table A5.1 gives a list of the codes and abbreviations used in the BSORT model to represent different tree species, along with the relevant full name for each species. Also given in this table are estimates of nominal specific gravity (NSG) for the wood of different tree species, expressed in units of oven-dried tonnes per cubic metre. These estimates have been taken from Lavers and Moore (1983). Where a value for NSG is not available for a given species, the relevant field in Table A5.1 is left blank but an indication is given of how a value available for another species has been assumed to be applicable. For example, no value for NSG is available for Austrian pine but the column marked ‘Equivalent’ in Table A3.1 indicates that the estimate for Corsican pine (PFCode = 2) has been assumed to apply for this species.

Table A5.2 gives a list of parameter estimates for allometric equations for estimating crown (woody branches plus foliage) mass and woody root biomass for different tree species. As for Table A5.2, columns marked ‘Equiv’ are used to indicate the nearest applicable parameter values when specific estimates are not available for a particular species. Further details are given in Appendix 3.

Table A5.3 gives a list of parameter estimates for estimating individual-tree stem volume for different tree species. As in earlier tables in this appendix, a column marked ‘Equiv’ is used to indicate nearest applicable parameter values when specific estimates are not available for a particular species. Further details are given in Appendix 4.

Reference

Lavers, G.M. and Moore, G.L. (1983) *The strength properties of timber*. Building Research Establishment Report CI/Sfb i(J3). Building Research Establishment: Garston.

Table A5.1. List of tree species represented in BSORT model also showing estimates of wood nominal specific gravity or assumed nearest equivalent.

PFCode		Species	Nominal Specific Gravity (NSG)	
			Equivalent	NSG
1	SP	Scots pine	1	0.42
2	CP	Corsican pine	2	0.4
3	LP	Lodgepole pine	3	0.39
4	AUP	Austrian pine	2	
5	MAP	Maritime pine	5	0.41
6	WEP	Weymouth pine	6	0.29
7	MOP	Mountain pine	3	
8	BIP	Bishop pine	2	
9	RAP	Radiata pine	2	
10	PDP	Ponderosa pine	2	
11	MCP	Macedonian pine	3	
12	XP	Other pines	1	
13	SS	Sitka spruce	13	0.33
14	NS	Norway spruce	14	0.33
15	OMS	Omorika spruce	15	0.33

PFCode		Species	Nominal Specific Gravity (NSG)	
			Equivalent	NSG
16	XS	Other spruces	14	
17	EL	European larch	17	0.45
18	JL	Japanese larch	18	0.41
19	HL	Hybrid larch	19	0.38
20	DF	Douglas fir	20	0.41
21	WH	Western hemlock	21	0.36
22	RC	Western red cedar	22	0.31
23	LC	Lawsons cypress	23	0.33
24	LEC	Leyland cypress	24	0.38
25	GF	Grand fir	25	0.3
26	NF	Noble fir	26	0.31
27	ESF	Silver fir	27	0.38
28	XF	Other firs (abies)	26	
29	JCR	Japanese cedar	22	
30	RSQ	Coast redwood	25	
31	WSQ	Wellingtonia	25	
32	XC	Other conifers	14	
33	MC	Mixed conifers	14	
34	OK	Oak	34	0.56
35	POK	Pedunculate oak	34	
36	SOK	Sessile oak	34	
37	ROK	Red oak	37	0.57
38	BE	Beech	38	0.55
39	SY	Sycamore	39	0.49
40	NOM	Norway maple	39	
41	AH	Ash	41	0.53
42	BI	Birch	42	0.53
43	PO	Poplar	43	0.35
44	SC	Sweet chestnut	44	0.44
45	HCH	Horse Chestnut	45	0.44
46	AR	Alder	46	0.42
47	CAR	Common alder	46	
48	GAR	Grey alder	46	
[illegible]	[illegible]	Red alder	46	
50	SAR	Sitka alder	46	
51	VAR	Green alder	46	
52	LI	Lime	52	0.44
53	CLI	Common Lime	52	
54	SLI	Small-leaved lime	52	
55	LLI	Large-leaved lime	52	
56	EM	Elm	57	
57	EEM	English elm	57	0.43
58	WEM	Wych elm	58	0.5
59	SEM	Smooth-leaved elm	57	
60	WCH	Wild cherry, Gean	60	0.5
61	BCH	Bird cherry	60	
62	HBM	Hornbeam	62	0.57
63	RON	Roble	39	
64	RAN	Raoul	64	0.37

PFCode		Species	Nominal Specific Gravity (NSG)	
			Equivalent	**NSG**
66	XB	Other broadleaves	39	
67	MB	Mixed broadleaves	39	

PFCode		Crown Biomass Function Params									Root Biomass		
		dbh <= 7cm				dbh > 7cm							
		Equiv	p	y	q	Equiv	a	p	y	q	Equiv	p	y
1	SP	14				1	4.35E-03	2.5138	1.32E-	0	1	2.1002	5.60E-
2	CP	14				2	0	1.721	1.40E-	0	2	2.3914	1.54E-
3	LP	14				3	4.35E-03	2.5138	1.32E-	0	3	2.4291	2.24E-
4	AUP	14				1					1		
5	MAP	14				1					1		
6	WEP	14				1					1		
7	MOP	14				1					1		
8	BIP	14				1					1		
9	RAP	14				1					1		
10	PDP	14				1					1		
11	MCP	14				1					1		
12	XP	14				1					1		
13	SS	13	1.459	5.22E-04	0	13	6.07E-03	2.5578	9.58E-	0.00E+0	13	2.68E+0	1.12E-
14	NS	14	1.459	5.22E-04	0	14	6.07E-03	2.5578	9.58E-	0.00E+0	14	2.49E+0	1.20E-
15	OMS	14				14					14		
16	XS	14				14					14		
17	EL	14				17	5.64E-03	2.1057	3.04E-	0	18		
18	JL	14				18	5.64E-03	2.1057	3.04E-	0	18	2.4291	2.24E-
19	HL	14				18					18		
20	DF	14				20	0	2.7169	3.46E-	-	20	2.421	2.18E-
21	WH	14				13					21	2.421	2.18E-
22	RC	14				13					22	2.3914	1.54E-
23	LC	14				13					22		
24	LEC	14				13					22		
25	GF	25	1.459	5.22E-04	0	25	6.07E-03	2.5578	9.58E-	0.00E+0	25	2.1002	5.60E-
26	NF	26	1.459	5.22E-04	0	26	6.07E-03	2.5578	9.58E-	0.00E+0	26	2.3914	1.54E-
27	ESF	27	1.459	5.22E-04	0	27	6.07E-03	2.5578	9.58E-	0.00E+0	25		
28	XF	14				25					25		
29	JCR	14				13					22		
30	RSQ	14				13					22		
31	WSQ	14				13					22		

PFCode		Crown Biomass Function Params									Root Biomass		
		dbh <= 7cm				dbh > 7cm							
		Equiv	p	y	q	Equiv	a	p	y	q	Equiv	p	y
32	XC	14				13					22		
33	MC	14				13					22		
34	OK	34	2.067	5.12E-05	0.7322	34	7.29E-03	3.6705	-	3.08E-	34	2.12E+0	1.49E-
35	POK	34				34					34		
36	SOK	34				34					34		
37	ROK	34				34					34		
38	BE	38	2	2.60E-04	0	38	6.86E-03	2.4658	1.92E-	0.00E+0	34		
39	SY	39	2.067	5.12E-05	0.7322	39	7.29E-03	3.6705	-	3.08E-	34		
40	NOM	39				39					34		
41	AH	41	2.067	5.12E-05	0.7322	41	7.29E-03	3.6705	-	3.08E-	34		
42	BI	42	2.067	5.12E-05	0.7322	42	7.29E-03	3.6705	-	3.08E-	34		
43	PO	14				1					34		
44	SC	39				38					34		
45	HCH	39				38					34		
46	AR	49				39					34		
47	CAR	49				39					34		
48	GAR	49				39					34		
49	RAR	49	2.067	5.12E-05	0.7322	49	7.29E-03	3.6705	-	3.08E-	34		
50	SAR	49				39					34		
51	VAR	49				39					34		
52	LI	39				39					34		
53	CLI	39				39					34		
54	SLI	39				39					34		
55	LLI	39				39					34		
56	EM	39				39					34		
57	EEM	39				39					34		
58	WEM	39				39					34		
59	SEM	39				39					34		
60	WCH	39				39					34		
61	BCH	39				39					34		
62	HBM	39				39					34		

PFCode		Crown Biomass Function Params									Root Biomass		
		dbh <= 7cm				dbh > 7cm							
		Equiv	p	y	q	Equiv	a	p	y	q	Equiv	p	y
63	RON	39				39					34		
64	RAN	39				39					34		
66	XB	39				39					34		
67	MB	39				39					34		

Table A5.3. List of tree species represented in BSORT model also showing parameter estimates for tree stem volume equations or assumed nearest equivalent. See Appendix 4 for further details. See Table A5.1 for list of full species names.

PFCode		Stem vol (conifers)				Stem vol (broadleaves)		
		Equiv	CONST	CH	CD	a	b	p
1	SP	1	9.82E+00	1.18E+00	1.14E-01			
2	CP	2	5.07E+00	1.75E+00	1.94E-01			
3	LP	3	8.86E+00	1.95E+00	6.90E-01			
4	AUP	2						
5	MAP	3						
6	WEP	1						
7	MOP	3						
8	BIP	2						
9	RAP	2						
10	PDP	2						
11	MCP	3						
12	XP	1						
13	SS	13	8.29E+00	1.77E+00	4.17E-01			
14	NS	14	9.94E+00	1.99E+00	6.51E-01			
15	OMS	14						
16	XS	14						
17	EL	17	5.562167	1.908473	0.426567			
18	JL	18	8.48E+00	1.79E+00	4.50E-01			
19	HL	18						
20	DF	20	1.04E+01	1.48E+00	3.26E-01			
21	WH	21	8.76E+00	1.96E+00	5.86E-01			
22	RC	22	1.06E+01	1.74E+00	6.31E-01			
23	LC	22						
24	LEC	22						
25	GF	25	7.03E+00	1.93E+00	3.74E-01			
26	NF	26	6.57E+00	2.04E+00	5.92E-01			
27	ESF	26						
28	XF	26						
29	JCR	22						
30	RSQ	25						
31	WSQ	25						
32	XC	14						
33	MC	14						
34	OK	34				-1.17E-02	7.65E-05	7.50E-01
35	POK	34						
36	SOK	34						
37	ROK	38						
38	BE	38				-1.43E-02	7.48E-05	7.50E-01

PFCode		Stem vol (conifers)				Stem vol (broadleaves)		
		Equiv	CONST	CH	CD	a	b	p
39	SY	39				-1.27E-02	7.37E-05	7.50E-01
40	NOM	39						
41	AH	41				-1.21E-02	7.77E-05	7.50E-01
42	BI	42				-9.18E-03	6.73E-05	7.50E-01
43	PO	43				-4.30E-03	4.35E-05	8.91E-01
44	SC	38						
45	HCH	39						
46	AR	39						
47	CAR	39						
48	GAR	39						
49	RAR	39						
50	SAR	39						
51	VAR	39						
52	LI	38						
53	CLI	38						
54	SLI	38						
55	LLI	38						
56	EM	38						
57	EEM	38						
58	WEM	38						
59	SEM	38						
60	WCH	39						
61	BCH	39						
62	HBM	38						
63	RON	39						
64	RAN	39						
66	XB	39						
67	MB	39						

Appendix 6. Data and key assumptions used in the FE Forecasting Model compared to FE volume Forecast

In the standard published production forecasts for FE, only land classified as high forest or windblown is included. Within these categories, land for which timber production is not the main management aim is removed and regarded as non-forecastable. For these crops all data used for forecasting timber production is surveyed and present in the crop database.

This study used all land that has a tree species i.e. includes arboreta, christmas trees etc. and therefore indicates the maximum potential wood fuel resource from FE land. Not all the crop used in this study will have all key forecasting values measured. The following assumptions were made if the data was not available:

Management model	Line thin, 1st thin at management table age, narrow spacing if wind hazard class < 5 and planted before 1970
	Line thin, 1st thin at management table age, 2.0m spacing if wind hazard class < 5 and planted 1970 or later
	No thinning, 1.5m spacing If planted before 1970
	No thinning, 2.0m spacing If planted 1970 or later
Planting year	2003
Wind hazard class	2 (crop can be thinned)
Yield Class	Minimum for the species

The data used for the wood fuel resource, yielded approximately 15% more volume (cubic metres over bark) than from the 2002 FE production forecast. It was assumed that the major cause of this change was the increase in area that was being included in the forecast. The table below shows the variation in area from the 2002 FE forecast and the 2003 wood fuel data by country. It can be seen that for GB there has been an overall increase of 16.03% in area included in the forecast, which corresponds to the increase in volume.

Country	**Area (ha)**		
Species Group	**2002 Forecast**	**2003 Wood Fuel**	**+/-**
England			
Pines	54,343.6	57,781.1	6.33%
Other Conifers	25,882.2	27,922.7	7.88%
Spruces	60,448.0	63,256.0	4.65%
Broadleaves	26,178.9	51,753.7	97.69%
	166,852.7	200,713.5	20.29%
Wales			
Pines	7,817.0	8,382.4	7.23%
Other Conifers	21,568.9	23,353.2	8.27%
Spruces	60,349.6	64,472.6	6.83%
Broadleaves	3,514.6	11,640.0	231.19%
	93,250.1	107,848.2	15.65%

Scotland			
Pines	105,127.9	116,664.4	10.97%
Other Conifers	37,039.2	39,688.5	7.15%
Spruces	255,928.8	275,391.9	7.60%
Broadleaves	2,123.2	25,880.4	1118.93%
	400,219.1	457,625.2	14.34%
Britain			
Pines	167,288.5	182,827.9	9.29%
Other Conifers	84,490.3	90,964.4	7.66%
Spruces	376,726.4	403,120.5	7.01%
Broadleaves	31,816.7	89,274.1	180.59%
	660,321.9	766,186.9	16.03%

The “Pines” category covers Scots pine, Corsican pine and lodgepole pine.
The “Spruces” category covers Sitka spruce and Norway spruce.
All other conifers are included in the “Other Conifers” category.
All broadleaves are included in the “Broadleaves” category.

The standing biomass estimate assumes that all the stands were felled in 2003, and is an estimate of the maximum potential biomass available in 2003. The same assumptions operate as in the forecast of biomass.

Appendix 7. Data and key assumptions used in the Private Sector Forecasting Model

	England	Wales	Scotland
Crop area data:	Crop areas by species and planting year class from the National Inventory of Woodland and Trees (NIWT). All areas of conifer species were included from both coniferous and mixed woodland.		
Volume assortment:	The assortment is calculated in 4 top-diameter classes; 7-14cm, 14-16cm, 16-18cm and over 18cm as cubic metres overbark standing volume.		
Unproductive area: Derived from the proportions of open space within woodland found by NIWT.	6.8% open space.	3.9% open space.	10.6% open space.
Timber potential: NIWT defines 4 classes of timber potential. Classes 1 and 2 capable of producing sawlogs and small roundwood Class 3, of small roundwood only, volume included in 7-14 cm size class. Class 4 not included in forecast.	Includes classes 1 and 2. Class 3 not significant in England.	Includes classes 1, 2 and 3.	Includes classes 1, 2 and 3.
Volume adjustment: Volume reductions applied to the forecast, based on NIWT data for extractability and stocking.	Overall adjustment: North England 4% Central England 4% South England 5%	Overall adjustment: Wales 2%	Overall adjustment: North Scotland 5% Mid Scotland 3% South Scotland 4%
Yield class:	Applied FE YC distribution.	Applied FE YC distribution.	Distribution based on TGA survey.
Thin/non thin:	1995 forecast; modified in North England.	1995 forecast, modified by TGA survey.	Proportions from TGA survey.
Rotation length: Amendments applied to principal species in each forecast.	1995 forecast as basis; amended to reflect extended YC range and variation in management: 25% as per basic assumption, 50% five years later and 25% 10 years later.	TGA survey; amended to reflect re-structuring: fell 25% 5 years early, fell 25% as per basic assumption, fell 25% 5 years later and 25% 10 years later.	TGA survey; amended to reflect re-structuring: fell 25% 5 years early, fell 25% as per basic assumption, fell 25% 5 years later and 25% 10 years later.
Crops already older than rotation age:	10.9 million m^3 beyond rotation	2.4 million m^3 beyond rotation	15.6 million m^3 beyond rotation

Private Sector forecasting model assumes a proportion of the standing volume will be felled over the first 20 years.	allocated: North 45%, Central 35%, South 35%	allocated: Wales 45%	allocated: North 35%, Mid 40%, South 45%
Crops beyond rotation age: PS forecasting assumes a proportion will be felled in first 20 years	10.9 million m^3 beyond rotation allocated North 45%, Central 35%, South 35%	2.4 million m^3 beyond rotation allocated 45%	15.6 million m^3 beyond rotation North 35%, Mid 40%, South 45%

Crop data: Crop areas by Species and planting year class from the National Inventory of Woodland and Trees (NIWT). All areas of conifer species were included from both Coniferous and Mixed woodland.

Yield Models : The full set of new Yield models were supplied by Mensuration Branch, Forest Research

Volume Assortment: The assortment is calculated in 4 top-diameter classes; 7-14cm, 14-16cm, 16-18cm and over 18cm as an overbark standing volume.

Appendix 8. Decision guide for quantifying environmental constraints at a Forest District level

A Project to Quantify the Wood Fuel Resource in Great Britain

A preliminary guide to harvesting wood fuel in the form of brashs from conventional forestry by the introduction of a decision making guide for harvesting managers

Produced jointly by the
Forestry Commission
and the
Forestry Contracting Association

Under funding support from
Department of Trade and Industry
Scottish Forestry Cluster
Welsh Development Agency
The Forest Industry

CONTENTS

A Project to Quantify the Wood Fuel Resource in Great Britain

A preliminary guide to harvesting wood fuel in the form of brash from conventional forestry by the introduction of a decision making guide for harvesting managers

1 The Project

There is considerable current interest in the use of wood as an energy source. Current and impending environmental legislation, and world-wide demands and agreements to reduce carbon emissions, are all factors driving the demand for wood as a fuel. The end product use will determine raw material requirement and wood fuel specifications. There is considerable potential for forestry to meet the demand for wood fuel from brash (needles, branches and stems usually <7cm diameter), standing deadwood, thinnings, or poor quality final crops in both conifer and hardwood crops. There is also the potential for the use of arisings from primary processing mills; this source will be heavily market dependent. Increasing legislation on the disposal of arisings from arboricultural operations offers the opportunity of another resource.

Previous studies have been carried out to assess the available resource, however they have lacked the ability to give immediate access to local knowledge of the resource, this will become increasingly important as smaller scale heat and CHP plants are developed. The availability of resource information in GIS format, to store and present the data, would provide an ideal opportunity to improve information flows to potential end users. In addition, data capture in GIS format would allow a greater ability to interrogate resource information on technical availability (harvesting systems, nutrient effects) and also by constraints imposed by contracts and price sensitivity linked to market competition.

There are several parts to the project. The part concerned with brash from conventional forests first calculates the production of 'lop and top' and then estimates how much of that biological potential is likely to be available once local site factors are taken into account

2 Methodology

The present exercise is designed to estimate, as accurately as possible, the local factors by visiting every district and working through a standard decision-making guide.

The production of quantitative information on available wood fuel from brash and residuals by individual FE Forest District harvesting managers using this guide is proposed as a multi stage process:

1. This guide will be sent electronically and hard copy to harvesting managers
2. The managers will digest the content and start to collate information
3. A visit from FCA or TDB (expected to take about 1 day of local staff time) will be made to assist the individual managers with understanding the process and assist in collating and completing the data collection spreadsheet which will then be sent electronically to Steve Smith, FR, Edinburgh
4. Steve will convert the area data to roundwood volumes from the roundwood production information currently held on the FE data base
5. Estimates of wood fuel will be produced using biomass relationships with stem volumes currently being produced by FR Alice Holt
6. The final information (incorporating arboricultural arisings, conversion products and short-rotation coppice) will be presented in GIS format on a specialist section of the FC web site.
7. Specific interrogation of the resource on a local basis will be available to potential developers on demand.

3 Harvesting wood fuel

Harvesting wood fuel for energy production from conventional forestry operations must be integral to the whole process of managing the woodland. Whatever management regime or operation is intended, it is important that all the objectives are fully thought through and implemented in a planned way. This will ensure that a clean wood fuel element is harvested whilst ensuring it is carried out in adherence to best environmental practice.

Normally, only material left above ground from harvested trees should be collected for wood fuel (not stumps or roots). The harvest could include:

- Tops and branches (Brash)
- Unmerchantable material including deadwood (Residuals)
- Small roundwood

There are a number of considerations that should be taken into account in estimating woodfuel availability; these are dealt with under the following section on harvesting constraints and which form important elements in the decision tree.

4 Harvesting constraints

The site constraints on harvesting must be considered as they will affect the choice of harvesting technology as well as the timing and scale of harvesting. As with conventional harvesting systems the terrain and soil type, weather conditions, water courses, provision of roadside facilities, siting of brash stores and wildlife habitats will need particular attention.

Specific to wood fuel harvesting as steps in the decision are the questions of the risk to soil fertility, conservation constraints (such as raptor sites or deadwood retention), critical load square exceedence (critical loads are the maximum load of a particular pollutant, e.g. acidifying sulphur in fresh water, which an ecosystem can tolerate without suffering adverse change) and ground damage. These questions are answered in sequence according to a decision tree as described later.

Before tackling the decision tree itself, there is some useful background information on the effect of soil type on the risk of soil fertility degradation, ground damage, harvesting times and the need for brash mats. This is followed by a short description of the range of possible woodfuel harvesting systems. The table below gives a useful guide in relation to soil type of the risk of ground damage and soil fertility degradation.

Table 1. Risk of soil fertility degradation (column 1) and ground damage (column 2) and on different soil types (column 3) from wood fuel harvesting

L	1	Brown earths
H	1	Podzols
H	3	Rankers
H	3	Skeletal soils
L	2	Limestone soils
H	2	Littoral soils without shallow water-table
H	3	Littoral soils with shallow / very shallow water-table
L	2	Surface-water gleys
L	2	Ground-water gleys
H	2	Ironpan soils
H	2	Shallow peaty soils <45cm deep
H	3	Peatland soils > 45cm deep
L	2	*Juncus* bogs

KEY

L - H = Risk to soil fertility (see Table 2)

1 - 2 - 3 = Risk of ground damage (see Table 3)

Table 2. Risk of soil fertility degradation

Risk Category	Soil Types (see Pyatt, 1982)
Low	Brown earths, Surface-water gleys, Ground-water gleys, *Juncus* Bogs.
High	Unflushed Peatland soils, *Molinia* bogs, Shallow peaty soils, Ironpan soils, Podzols, Littoral soils, Rankers and Skeletal soils.

Table 3. The soil groups for the decision tree based on ground damage potential.

Soil Group (as per decision tree)	Soil Group Description	Timing of harvesting	Brash mats
1 (Low risk of ground damage)	Brown earths, Podzols, Rankers, Skeletal soils, Limestone soils and Littoral soils except Sand with shallow or very shallow water-table.	All year	As required on wetter areas, main extraction routes, areas of steep ground
2 (Medium risk of ground damage)	Shallow peaty soils (peat <45 cm deep), Groundwater gleys, Surface Water Gleys, Ironpan soils.	All year	As required on wetter areas, main extraction routes, areas of steep ground. Requirement obviously dependant on seasonal/weather conditions
3 (High risk of ground damage)	Peatland soils (>45 cm deep), Littoral soils with shallow water table.	No wood fuel harvesting (except cable-crane)	

5 Harvesting systems

This section is not intended to be a full description of all wood fuel harvesting systems. It is merely a precis of options to provide the harvesting manager with sufficient background information to enable a series of value judgements to be made to assist in using the decision tree laid out in Annex1

The choice of harvesting methods and machinery will depend on the specific site sensitivities, the requirements of the end user for a specific product, the scale of the operation and the forest layout, and will be determined as an integral part of overall harvesting. The scale of equipment varies from hand-held tools to large scale harvesting machinery.

There are three main wood fuel harvesting systems:
1. Whole tree harvesting
2. Whole tree chipping
3. Second pass brash harvesting

Table 4 shows which types of woodfuel harvesting sytems can be used on various soil types.

- **Table 4. Soil groups and applicable harvesting systems**

Soil Group	Applicable Harvesting Systems
1	Whole Tree Harvesting Whole Tree Chipping Second Pass Brash Harvesting
2 (Summer/dry)	Whole Tree Harvesting Whole Tree Chipping Second Pass Brash Harvesting
2 (Winter/wet)	Whole Tree Harvesting Second Pass Brash Harvesting

1. **Whole-tree harvesting.** Single-phase harvesting operations involve the whole tree being removed from the stump to the forest road. The tree is then divided into conventional stem wood and energy products. Extraction methods include the use of forwarders with clambunks, skidders or cable cranes for off-ground transport of the tree from stump to landing. The brash can then be compressed using brash compression machinery at roadside, comminuted directly at roadside or transported in uncomminuted form. Previous trials (FCA, 2000 – Forest Residue Due Diligence, Assessment, Proving and Transport trials) have shown that economic compression costs can be obtained when compressing at roadside from the brash bins / piles. The advantage of this system is a high brash yield of clean un-contaminated wood fuel, the disadvantage however is that previous trials have shown that the system needs to be relatively 'hot' to prevent brash bins being pushed over the forest landing and becoming contaminated and unreachable with machinery.

Where whole-tree harvesting is used, the type of equipment will depend on the site,

2. **Whole-tree chipping**
Whole-tree chipping (terrain chipping). The whole tree, usually of smaller size, are felled and then chipped at the stump and the chips extracted to the landing. This system is more common in Scandinavia where whole trees from thinnings are chipped as a fuel source. The advantages of this system are a clean source of uncontaminated fuel, the disadvantages are the high capital cost associated with the comminution equipment, the intense logistics associated with the operational management of the system and the site limitations due to the absence of a brash mat.

Whole-tree chipping (landing chipping)
The whole tree is felled and then extracted (off ground by forwarder to avoid contamination) to the landing. The chipping of the whole tree takes place at the landing and the chips blown into road transport. The advantages of this system are a clean source of uncontaminated fuel, the disadvantages are the large landing space required, high capital cost associated with the comminution equipment, the intense logistics associated with the operational management of the system and the site limitations due to the possible absence of a brash mat.

3. **Second-pass brash harvesting.** The stem wood is removed in a first-pass conventional shortwood harvesting operation. The woodfuel is removed in a second-pass operation:

- **Terrain Chipping** – the brash material is chipped at stump and extracted to roadside. The chipper and bin are mounted on a forwarder base, when full the forwarder extracts the chip to roadside for emptying into a steel container. On longer extraction distances a secondary extraction unit with chip holding bin is used. The disadvantages of this system are again the intense logistics associated with the operational management of the system, the site limitations due to the absence of a brash mat and the potential contamination of the wood fuel element, which can increase comminution costs.

- **Brash Extraction** – the brash is extracted by forwarder and stock piled at roadside. The material can then be chipped directly at roadside with transport to the plant in comminuted form or the material can be transported in un-comminuted form to a central comminution and storage facility. The advantages are utilising existing harvesting equipment and the use of a central comminution facility, which offers economies of scale. The disadvantage being that the low bulk density of the material in uncomminuted form prevents economic extraction and haulage weights being achieved, therefore only really suitable for short extraction and haulage distances.

- **Brash Compression** - the brash is compressed or 'bundled' at stump and the compressed brash log (Fiberlog) is extracted to roadside.   The latest generation of compression machines produces a brash log with a diameter of 70 centimetres (cm) and a variable length. This allows the full utilisation of both extraction and haulage equipment. The fiberlogs are then taken directly to the plant or to a central comminution facility.

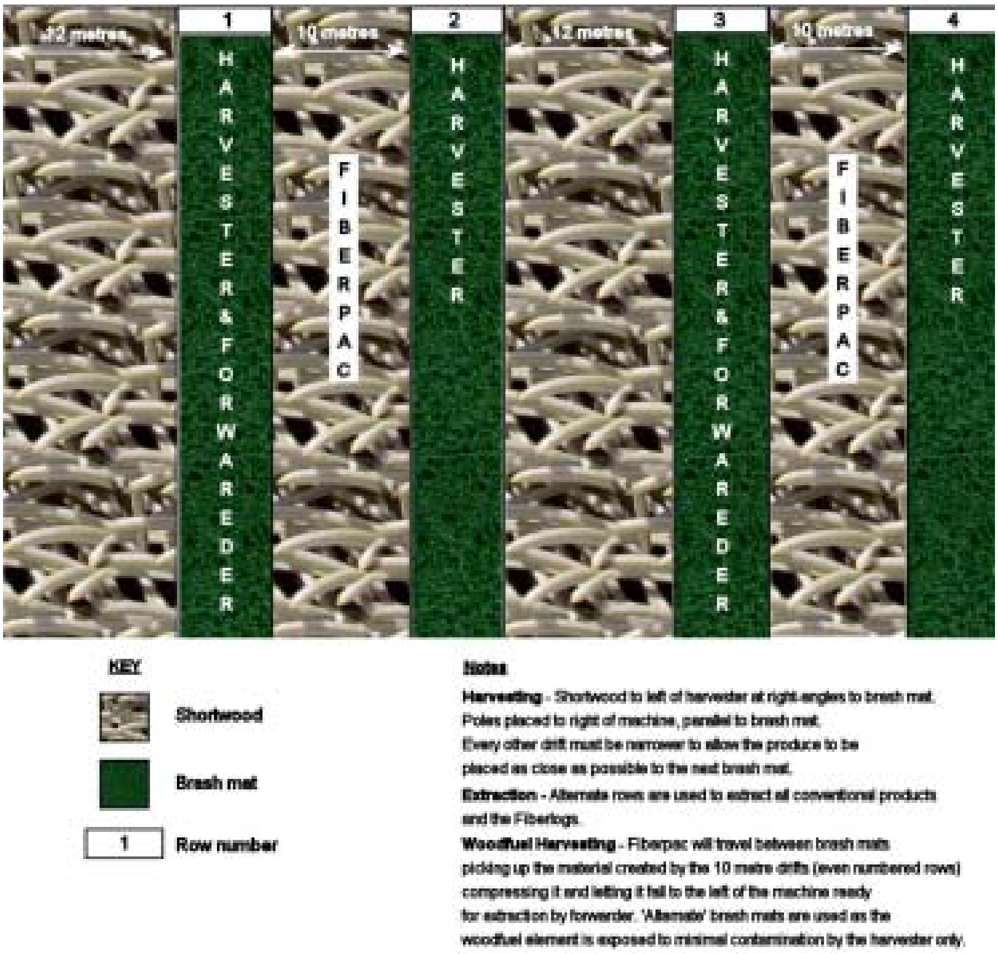
The use of brash compression systems has advantages in that it utilises existing extraction and transport equipment (no further capital investment needed at this level), offers the opportunity for economies of scale in central comminution facilities and offers the opportunity to obtain economic haulage weights. The disadvantage is that there is a high capital cost associated with the compression machinery and the effect of long term storage of the compressed fiberlogs is yet unknown (currently being analysed in a 18 month storage trial by the Forestry Contracting Association).

During previous compression trials (FCA, 2000 – Forest Residue Baling Due Diligence Assessment. Proving and Transport Trials) two different harvesting systems were developed for extraction of brash when using the Fiberpac machine, a description of these systems as per the harvesting trial is shown below:

Alternate Brash Mat Method

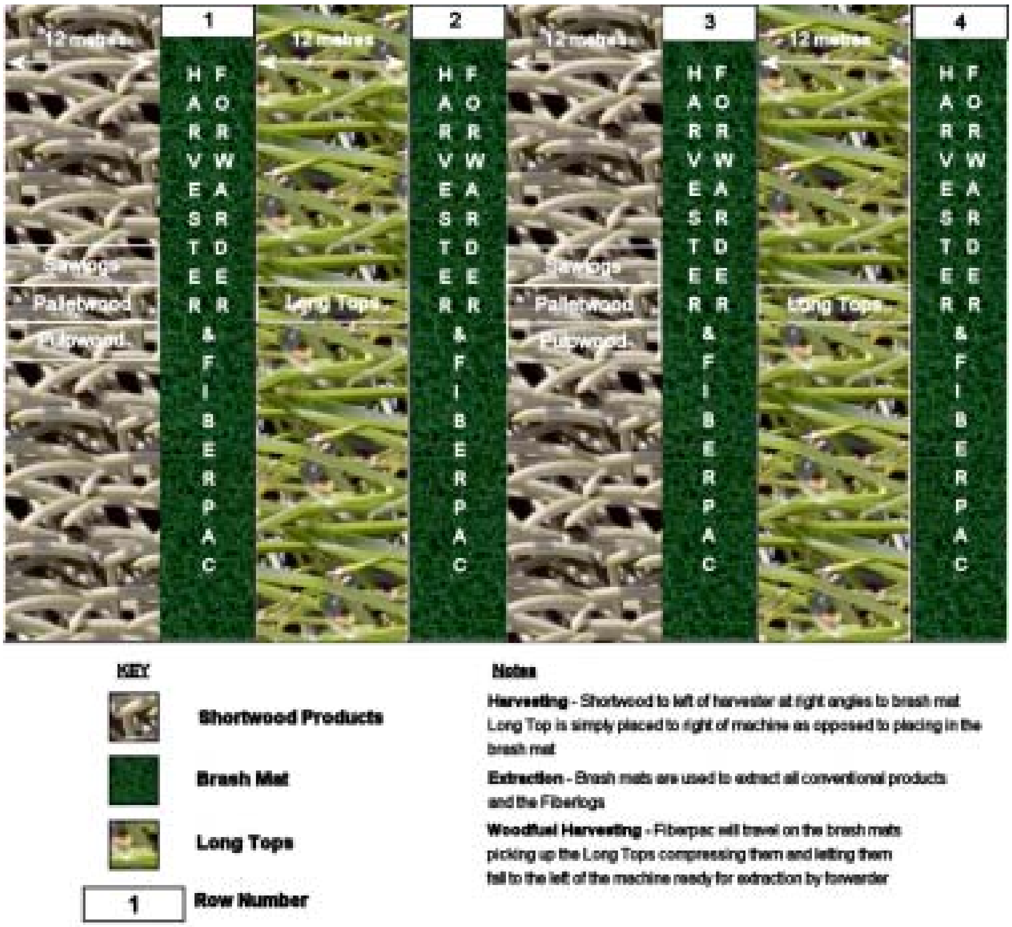
In conventional shortwood harvesting the harvester cuts a drift of approximately 12 metres (m), all brash is placed under the machine wheels and the produce is placed to the left of the operator/direction of travel. The forwarder then travels on these brash mats extracting the produce.

By cutting alternate drifts of 10 and 12 m the harvester, when cutting the 10 m drift, is able to place the produce next to the brash mat created by the 12 m drift. The brash mat created by the 12 m drift is then used by the forwarder to extract all the produce. By adopting this method the brash mat created by the 10 m drift is exposed to minimal contamination as the harvester has only travelled on it once. The Fiberpac unit then travels between the brash mats lifting and compressing the brash mat created by the 10 m drift. The Fiberlogs are then extracted by the forwarder using the brash mat created by the 12 m drift.



Long tops and mat minimisation method

The site is harvested using the shortwood system, normal drift width is retained by the harvester during cutting. All timber products are placed to the left of the operator/direction of travel; the branches and tops are placed to the right of the machine/direction of travel in windrows. Correct orientation of the material is crucial to allow ease of feeding by the Fiberpac machine. With this system, dependant on the ground conditions within the site, the quantity of brash required for machine flotation can be varied as required by the harvester operator. The length of the tops is dependent on the product specification being cut, therefore the wood fuel yield will fluctuate, as it is dependent on the small roundwood markets. The Fiberpac machine travels along the drifts collecting and compressing the material prior to extraction by forwarder. The productivity of the harvester increased, as the tops did not have to be cross-cut and orientated to form the brash mat.



In all of the above wood fuel harvesting systems there is a need for integration with the conventional roundwood harvesting operation. The decision to harvest the wood fuel element must be made at the planning stage to ensure maximum recovery, minimal contamination and the correct choice of harvesting system.

6 Decision Tree

In order for the available wood fuel resource to be calculated a decision tree has been created that will determine how much of the total forecastable volume (TFV), based on area weighted by yield class, is likely to be suitable as a wood fuel resource. The decision tree will utilise the forest district harvesting manager's local knowledge to estimate the available resource by area. FE Edinburgh will convert the area data to roundwood volumes from the roundwood production information currently held on the FE data base. Estimates of wood fuel will be produced using biomass relationships with stem volumes currently being produced by FR Alice Holt.

Annex 1 gives the diagrammatic decision tree to aid in calculating the area from which brash can be taken, the following steps should be followed to allow the volume suitable as a wood fuel resource to be determined.

Step 1: Note the total area of forest in the district **[Box 1]**.

Step 2: Note the area covered by the particular "**species group**" being considered (1 of 4 - **Spruce**, **Pine**, **Other Conifers** or **Broadleaves**) **[Box 2]**. If an area is of mixed species (e.g SS and LP), the interrogation of the database will give total area of a given species within the district and this will include those areas covered by that species in mixtures. No separate analysis is therefore required for areas of mixtures.

Step 3: The decision guide is then divided by soil types 1-3, for a definition of these soil types refer to table 3 in the text. Enter the area of each soil type **[Boxes 3, 11 & 19]**. Use the following instructions for soil types 1 & 2, soil type 3 is dealt with later.

Instructions for soil type 1 & 2

Step 4: Is restoration felling required on areas of the district for the species group? If YES then note the area. It is assumed that all this potential product will be AVAILABLE FOR WOOD FUEL **[Diamond A & Boxes 4 & 12]**.

Step 5: Is any of the area covered by the species group on slopes / areas likely to be extracted by cable-crane? **[Diamond B]**. If YES note the area **[Boxes 5 & 13]**. AVAILABLE FOR WOOD FUEL

Step 6: Are there any conservation constraints which could limit the amount of brash available from the district? If YES then note the area NOT AVAILABLE **[Diamond C & Boxes 6 & 14]**.

Step 7: Is any of the particular species group on Critical Load Exceedence squares? If YES then note the percentage area affected. Please take into account the areas within Critical Load Exceedence squares that are to be harvested by cable crane because brash from these areas will be available in spite of Critical Load considerations **[Diamond D & Boxes 7 & 15]**. NOT AVAILABLE

Step 8: Is there a Risk to soil fertility from whole tree harvesting on the site e.g. has soil fertility been shown to be low historically. Refer to table 2 for soil type/fertility relationship. If risk is HIGH then note the area **[Diamond E & Boxes 8 & 16]**. NOT AVAILABLE

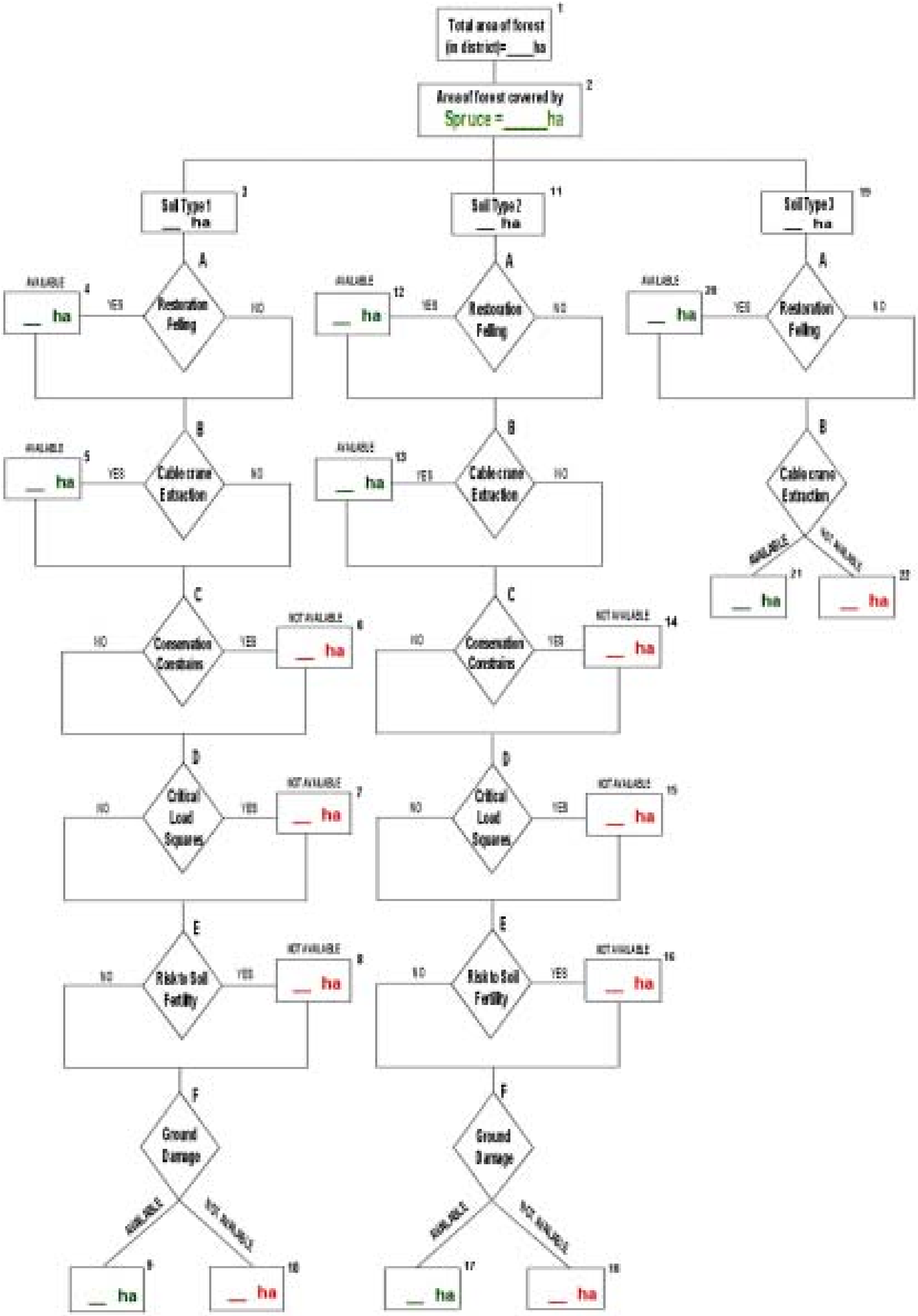
Step 9: Refer again to table 3 for definition of soil type. This step **[Diamond F]** refers specifically to the potential for ground damage due to soil type characteristics. Therefore the AVAILABLE figure **[Boxes 9 & 17]** and the NOT AVAILABLE figure **[Boxes 10 & 18]** need to take into account the figures previously inputted **[Boxes 4, 5, 6, 7, 8]** for soil type 1 and **[Boxes 12, 13, 14, 15, 16]** for soil type 2. The figures inputted for specific soil types **[Boxes 10 & 18]** should also take into account, based on your local knowledge areas that may require retention of brash for main extraction routes, wet areas and steep areas i.e. NOT AVAILABLE

Instructions for soil type 3
Step 10: Is restoration felling required on areas of the district for the species group? If YES then note the area. It is assumed that all the potential product will be AVAILABLE FOR WOOD FUEL **[Diamond A & Box 20]**.

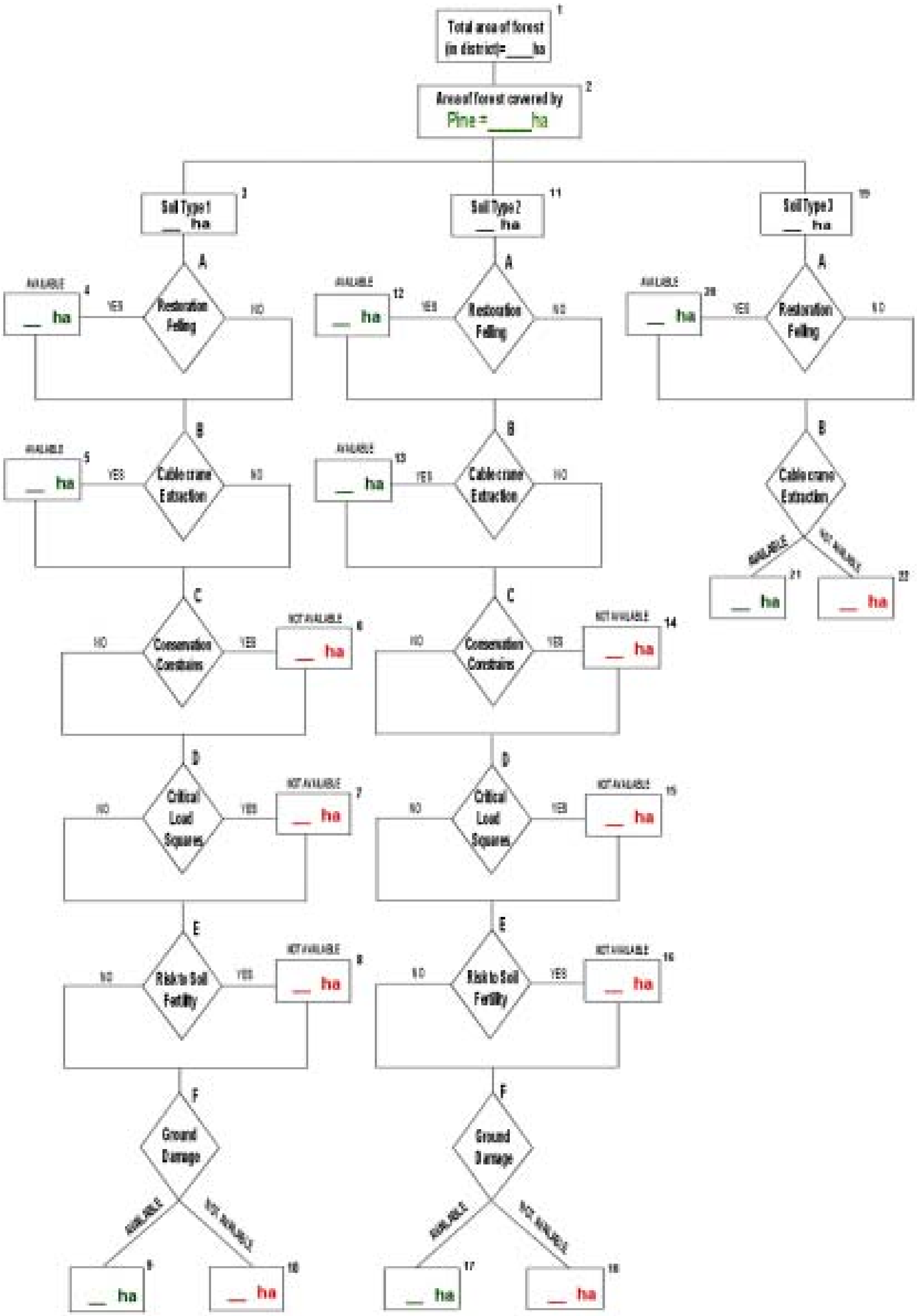
Step 11: Is any of the area covered by the species group on slopes / areas likely to be extracted by cable-crane? **[Diamond B]**. In reference to table 3, soil type 3 with its high risk of soil damage is only considered AVAILABLE FOR WOOD FUEL from the areas calculated from Restoration felling **[Diamond A, Box 20]** and Cablecrane extraction **[Diamond B, Box 21]**. All other areas within soil type 3 are NOT AVAILABLE. Therefore the AVAILABLE FOR WOOD FUEL figure should be the sum of **[Box 20 & 21]**.

Data Input
All data should be inputted onto the enclosed spreadsheet. Please ensure that the AVAILABLE FOR WOOD FUEL figure and the NOT AVAILABLE figure equal the soil type area (ha) and that the area of the 3 soil types equals the area covered by the species group.

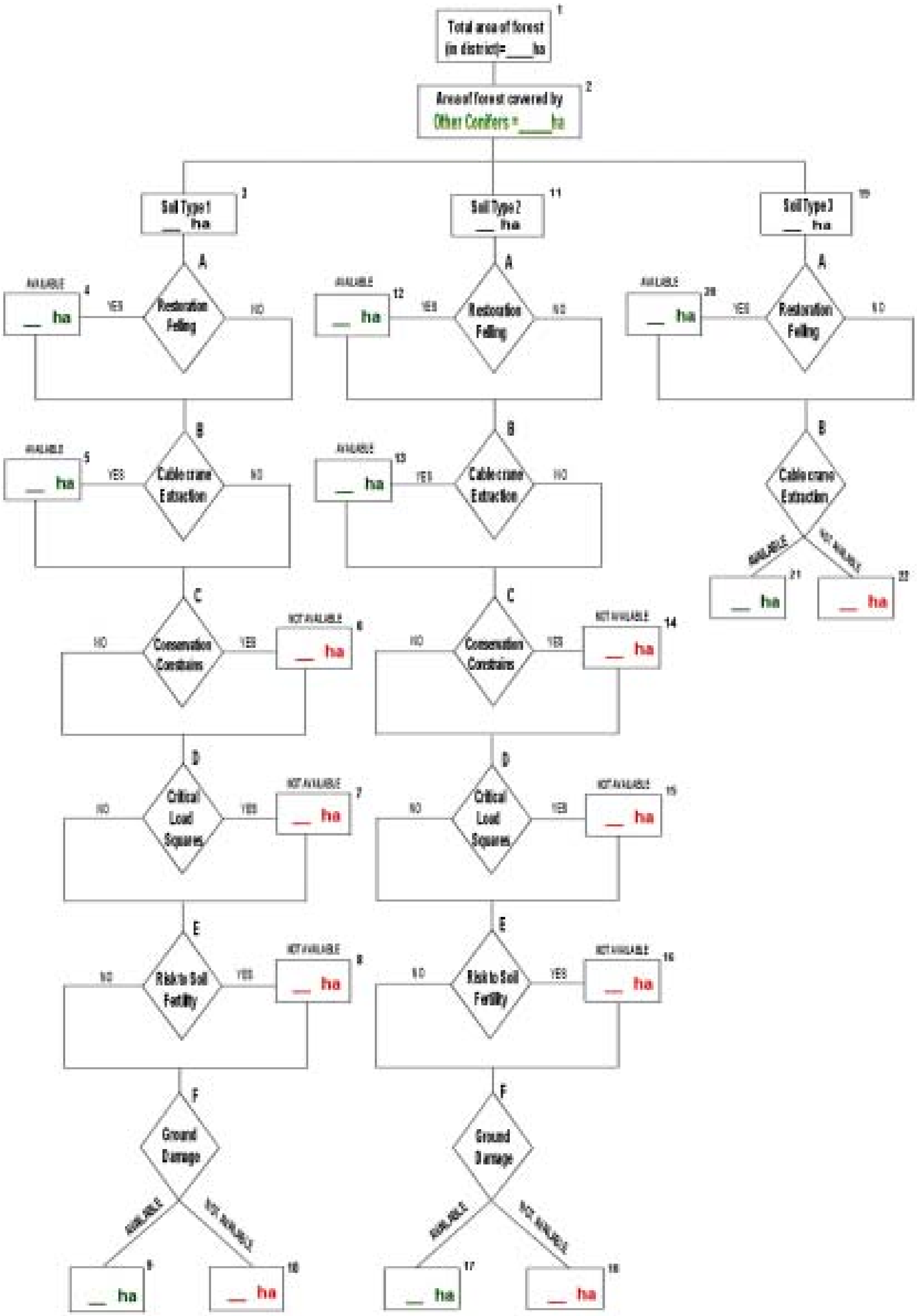
This process is to be used separately for each species group.

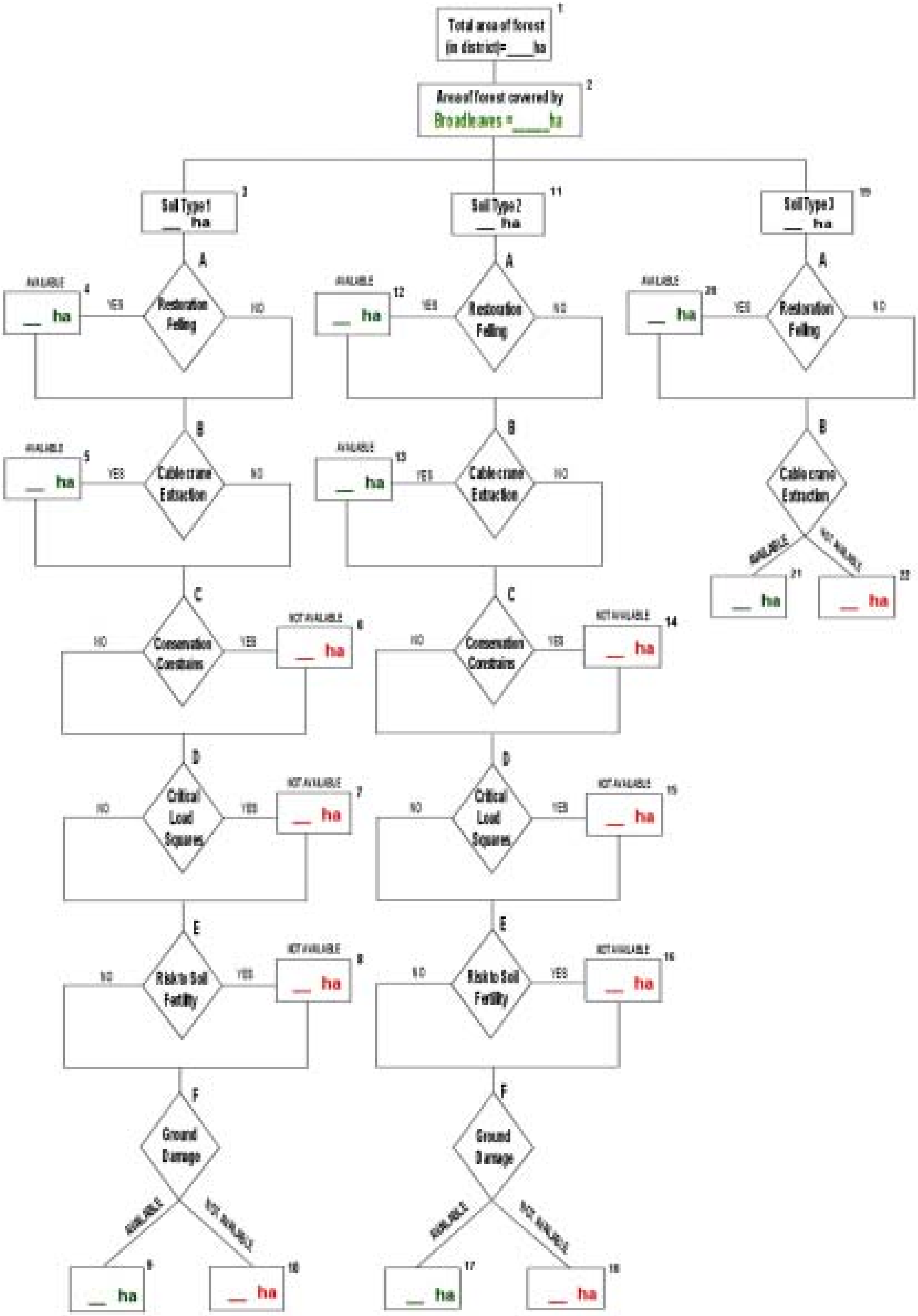


Total area of forest (in district)=___ha
Area of forest covered by Spruce = _____ha
Soil Type 1 __ ha
Soil Type 2 __ ha
Soil Type 3 __ ha
Restoration Felling
Cable crane Extraction
Conservation Constrains
Critical Load Squares
Risk to Soil Fertility
Ground Damage
YES
NO
AVAILABLE
NOT AVAILABLE
__ ha



Total area of forest (in district)=___ha
Area of forest covered by Pine =_____ha
Soil Type 1 __ ha
Soil Type 2 __ ha
Soil Type 3 __ ha
Restoration Felling
Cable crane Extraction
Conservation Constrains
Critical Load Squares
Risk to Soil Fertility
Ground Damage
YES
NO
AVAILABLE
NOT AVAILABLE
__ ha


Total area of forest (in district) = ___ ha
Area of forest covered by Other Conifers = ___ ha
Soil Type 1 __ ha
Soil Type 2 __ ha
Soil Type 3 __ ha
Restoration Felling
Cable crane Extraction
Conservation Constrains
Critical Load Squares
Risk to Soil Fertility
Ground Damage
AVAILABLE
NOT AVAILABLE
YES
NO
__ ha


Total area of forest (in district)=___ha
Area of forest covered by Broadleaves = ____ha
Soil Type 1 __ ha
Soil Type 2 __ ha
Soil Type 3 __ ha
Restoration Felling
Cable crane Extraction
Conservation Constrains
Critical Load Squares
Risk to Soil Fertility
Ground Damage
AVAILABLE
NOT AVAILABLE
YES
NO
__ ha

Appendix 9. Average environmental constraints at a Forest District and Regional level in Forest Enterprise.

Area code	Area	Percent available			
		Species group			
	All Forest Districts	**Spruce**	**Pine**	**Other con.**	**Blvs**
101	SHERWOOD AND LINCS	62	64	59	58
103	EAST ANGLIA	19	62	56	54
104	NORTHANTS	70	70	70	65
112	KIELDER	13	16	21	0
113	NORTH WEST ENGLAND	43	40	49	0
117	NORTH YORK MOORS	38	38	38	41
302	SOUTH EAST ENGLAND	61	46	57	59
304	NEW FOREST	38	16	16	0
312	WEST MIDLANDS	32	31	38	0
314	PENINSULA	35	45	55	59
317	FOREST OF DEAN	64	72	65	61
410	COED Y GORORAU	46	55	59	0
413	COED Y MYNYDD	32	31	32	31
416	COED Y CYMOEDD	24	34	40	26
418	LLANMYDDFRI	32	43	53	69
501	WEST ARGYLL	15	10	7	0
503	LORNE	21	13	21	0
504	TAY	50	47	50	75
511	MORAY	0	0	0	0
513	BUCHAN	4	0	0	0
514	KINCARDINE	28	21	30	0
516	DORNOCH	11	2	0	0
517	INVERNESS	10	2	27	0
518	FORT AUGUSTUS	10	0	2	0
519	LOCHABER	7	1	5	0
701	COWAL AND TROSSACHS	25	34	22	0
704	SCOTTISH LOWLANDS	5	4	14	0
710	GALLOWAY	2	3	13	0
714	AE	14	10	17	4
715	SCOTTISH BORDERS	16	4	6	9
	English Regions	**Spruce**	**Pine**	**Other con.**	**Blvs**
1	NORTH EAST	13	16	21	0
2	NORTH WEST	43	40	49	0
3	YORKS & HUMBER	38	38	38	41
4	EAST MIDLANDS	65	66	63	60
5	WEST MIDLANDS	32	31	38	0
6	EAST OF ENGLAND	21	62	57	54
7/8	SOUTH EAST	52	34	41	36
9	SOUTH WEST	47	50	52	49

Appendix 10. Average environmental constraints at a Forest District and Regional level in the private sector

Area code	Area	Percent available			
		Species group			
	All Forest Districts	**Spruce**	**Pine**	**Other con.**	**Blvs**
101	SHERWOOD AND LINCS	62	64	59	58
103	EAST ANGLIA	19	62	56	54
104	NORTHANTS	70	70	70	65
112	KIELDER	13	16	21	0
113	NORTH WEST ENGLAND	43	40	49	0
117	NORTH YORK MOORS	38	38	38	41
302	SOUTH EAST ENGLAND	61	46	57	59
304	NEW FOREST	38	16	16	0
312	WEST MIDLANDS	32	31	38	0
314	PENINSULA	35	45	55	59
317	FOREST OF DEAN	64	72	65	61
410	COED Y GORORAU	46	55	59	20
413	COED Y MYNYDD	32	31	32	31
416	COED Y CYMOEDD	24	34	40	26
418	LLANMYDDFRI	32	43	53	69
501	WEST ARGYLL	15	10	7	10
503	LORNE	21	13	21	10
504	TAY	50	47	50	75
511	MORAY	30	15	20	20
513	BUCHAN	30	15	20	20
514	KINCARDINE	25	21	30	20
516	DORNOCH	11	2	5	10
517	INVERNESS	20	10	27	10
518	FORT AUGUSTUS	10	10	10	10
519	LOCHABER	10	10	10	10
701	COWAL AND TROSSACHS	25	34	22	10
704	SCOTTISH LOWLANDS	40	10	20	10
710	GALLOWAY	10	10	10	10
714	AE	25	10	15	10
715	SCOTTISH BORDERS	40	10	20	10
	English Regions	**Spruce**	**Pine**	**Other con.**	**Blvs**
1	NORTH EAST	13	16	21	0
2	NORTH WEST	43	40	49	0
3	YORKS & HUMBER	38	38	38	41
4	EAST MIDLANDS	65	66	63	60
5	WEST MIDLANDS	32	31	38	0
6	EAST OF ENGLAND	21	62	57	54
7/8	SOUTH EAST	*52	*34	*41	*36
9	SOUTH WEST	47	50	52	49

*** Note: includes London**

Appendix 11 Average brash recovery rates

Cablecrane sites	80%
Restoration felling sites	80%
All other areas	70%

Appendix 12. Arboricultural Contractor and Local Authority Tree Officer Arboricultural woodfuel questionnaire.

Woodfuel Resource UK Study 2002

The Forestry Commission and Forestry Contracting Association are undertaking a woodfuel resource study (see attached project profile). Bioenergy, including woodfuel has the potential to generate energy, in the form of both heat and electricity, from material that would otherwise not be utilised. Four potential sources of woodfuel are being considered:

- Harvesting brash from forests ('lop and top', pre-commercial thinning etc.)
- Residues from utilities line-clearance
- Residues from arboricultural work
- Residues from track and roadside maintenance

The results from each sector will be combined in a web-based GIS to show the woodfuel potentially available by region. We are asking Arboricultural Contractors and Tree Officers throughout Britain to estimate, as closely as possible, the volume or weight of brash from tree-work and grounds maintenance in each area of Britain falling into the latter three categories.

QUESTIONS

Name: ______________________________

Contact phone / e-mail: ______________________________

Where do you work / What area do you cover? ______________________________

____

Where do you dispose of the majority of the woody material / arisings produced?

____

(Please be as accurate as possible, including postcode of offices, closest large town and local authority).

Total amount of woody material per annum? ____________ **Cubic metres or tonnes***
(This figure should include ALL stemwood, branchwood, chip etc.)

Form of Arb. arisings:

Material produced	**① Percent of Total**	**Percent of ① estimated to be available for woodfuel**
Stemwood		
Branchwood		
Chipped		
Foliage		

Thank you for participating. If you have any difficulties with the above please contact Ben Hudson via the address below.

Please return to:

Forestry Contracting Association (Research and Development)
Dalfling, Blairdaff

Inverurie
Aberdeenshire
AB51 5LA
Tel: 01467 651368, Fax: 01467 651595, E-mail: ben@fcauk.com

Appendix 13. Units, terms and conversions

1. Energy units

Energy is normally expressed in terms of thousands of joules.

Kilojoules	KJ				
Megajoules	MJ	=	1,000 KJ		
Gigajoules	GJ	=	1,000,000 KJ	=	1,000 MJ

Energy supplies and consumption by end-users (electricity and gas bills) are usually expressed in terms of kilowatt-hours (kWh). Large quantities of energy are expressed in megawatt-hours (MWh) or gigajoules (GJ).

Conversion between GJ and MWh is –

3.6 GJ = 1 MWh

or MWh ÷ 3.6 = 1 GJ

Still larger quantities of energy are expressed in gigawatt hours (GWh) or terawatt hours (TWh)

1 GWh	=	1,000 MWh	=	1,000,000 kWh
1 TWh	=	1,000 GWh	=	1,000,000 MWh

2. Woodfuel units

Woodfuel quantities are also expressed in various ways.

odt = oven dried tonnes (at 0% Moisture Content)

tonnes = tonnes of fuel at a specified Moisture Content usually in the range 0 to about 60%

cubic metres (m^3) loose = method of expressing volumes of woodchips or bark

cubic metres (m^3) stacked = method of expressing volumes of carefully stacked fuelwood

cubic metres (m^3) solid = equivalent volume of solid wood

general rules-of-thumb exist for converting between these measures

	Loose m^3	Stacked m^3	Solid m^3
1 loose m^3	1.00	0.60	0.40
1 solid m^3	2.50	1.49	1.00

1 solid m^3 = 2.5 loose m^3 = [2 MWh (approximately)]

3. Wood density

Species	Density (kg dry matter per m^3)
beech/oak	580
ash	570
sycamore	540
birch	510
spruce	390

4. Energy content of wood

The dry-fibre calorific value varies a little between tree species and between the elements of the tree for each species. The table below indicates the range of oven dry calorific values for a range of species in Gigajoules per oven dry tonne (GJ odt^{-1}).

Species	Stem without bark	Bark	Whole stem	Crown	Whole tree
Sitka spruce					19.6
Norway spruce	19.05	18.80	19.02	19.77	19.29
Scots pine	19.31	19.53	19.33	20.23	19.52
sycamore	19.91	20.00		20.33	
silver birch	18.61	22.52	19.15	19.53	19.29
red maple	20.13	19.08		19.93	

5. Definition of Moisture Content

Moisture content is usually defined as the water mass as a proportion of the fresh weight of the material. So the general range of woodfuel moisture content is from about 60% (freshly harvested) to 20% (dried). By definition oven dried material is at 0% moisture content - this level of drying is not normally used operationally.

$$\frac{(\text{fresh weight} - \text{oven dry weight})}{\text{fresh weight}} \cdot 100$$

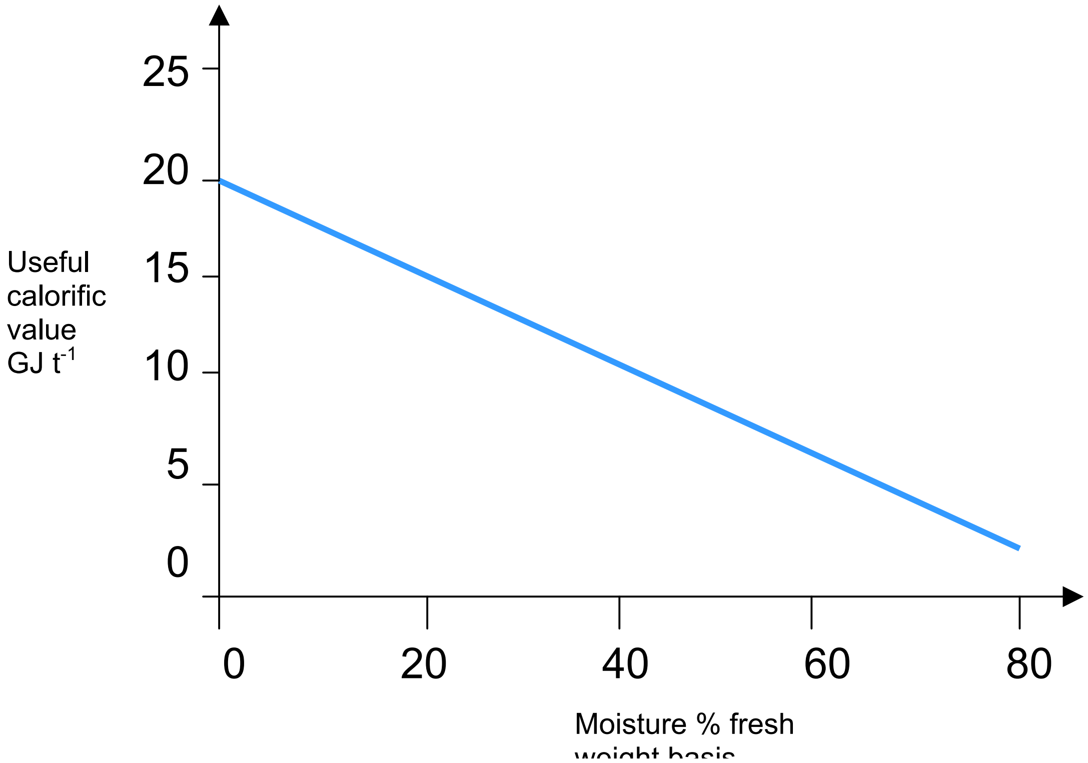
Moisture content is sometimes calculated on a dry weight basis, i.e. the water mass as a proportion of the oven dry weight.

$$\frac{(\text{fresh weight} - \text{oven dry weight})}{\text{oven dry weight}} \cdot 100$$

Using this calculation, it is possible to have moisture contents of over 100% for freshly harvested timber.

6. Influence of moisture content

Moisture does not affect the inherent energy value of the wood but normally wood contains water which means that energy has to be used to evaporate the water; this reduces the useful, or net, energy content per unit weight of fresh material.



The relationship between moisture content and net calorific value is illustrated in the chart above and is given by the equation –

$$Q_{net,ar} = Q_{net,d} \times \frac{(100 - M_{ar})}{100} - 0.02441 \times M_{ar} \qquad (1)$$ [1]

where $Q_{net,ar}$ = net calorific value, as received

$Q_{net,d}$ = net calorific value, dry

M_{ar} = Moisture Content, as received

Appendix 14. Distribution of the number of tree work contractors and number of contractors who responded to the questionnaire in Forestry Commission Forest Districts.

F.C. Forest Districts	Number of contractors	Number of responses	% responses
England	**1,943**	**126**	**6.5**
South East England	565	49	9
New Forest	66	2	3
Peninsula	134	12	9
Forest of Dean	177	10	6
West Midlands	147	7	5
Northants	106	7	7
East Anglia	160	9	6
Sherwood & Lincs	188	6	3
North West England	204	12	6
North York Moors	141	7	5
Kielder	55	5	9
Scotland	**126**	**16**	**12.7**
Scottish Borders	12	1	8
AE	8	0	0
Galloway	4	0	0
Scottish Lowlands	55	4	7
Cowal & Trossachs	4	1	25
West Argyll	2	0	0
Lorne	1	1	100
Tay	25	5	20
Lochaber	1	1	100
Fort Augustus	1	0	0
Inverness	3	0	0
Dornoch	2	1	50
Moray	0	0	0
Buchan	3	0	0
Kincardine	5	2	40
Wales	**105**	**8**	**7.62**
Coed y Cymoed	44	4	9
Coed y Mynydd	11	1	9
Coed y Gororau	25	3	12
Llanymddyfri	25	0	0
GB total	**2,174**	**150**	**7**

Appendix 15. Estimated* arboricultural arisings for Forest Districts by the material produced (stem wood, branch wood, wood chips and foliage).

F.C. Forest Districts	Stemwood (odt/year)	Branchwood (odt/year)	Wood chips (odt/year)	Foliage (odt/year)	Total arisings (odt/year)
England	**241,443**	**85,568**	**103,513**	**14,500**	**445,024**
South East England	93,624	25,798	36,336	4,111	159,869
New Forest	2,681	180	4,670	180	7,711
Peninsula	3,702	3,680	2,057	158	9,597
Forest of Dean	14,770	5,916	7,111	688	28,485
West Midlands	4,253	3,748	2,239	1,070	11,310
Northants	13,144	2,527	10,669	495	26,835
East Anglia	13,774	7,636	5,605	703	27,718
Sherwood & Lincs	30,715	12,557	13,190	1,566	58,028
North West England	10,574	16,074	11,346	1,451	39,445
North York Moors	51,236	3,396	6,051	3,033	63,716
Kielder	2,970	4,056	4,239	1,045	12,310
Scotland	**5,766**	**3,872**	**5,307**	**1,201**	**16,146**
Scottish Borders	714	570	434	258	1,976
Ae	452	372	348	140	1,312
Galloway	226	186	174	70	656
Scottish Lowlands	2,295	925	2,546	119	5,885
Cowal & Trossachs	468	352	566	16	1,402
West Argyll	113	93	87	35	328
Lorne	57	46	44	17	164
Tay	484	468	240	160	1,352
Lochaber	57	0	6	0	63
Fort Augustus	57	46	47	17	167
Inverness	169	140	140	52	501
Dornoch	113	93	93	35	334
Moray	0	0	0	0	0
Buchan	170	139	140	52	501
Kincardine	391	442	442	230	1,505
Wales	**3,565**	**4,325**	**2,123**	**987**	**11,000**
Coed y Cymoed	1,279	900	879	521	3,579
Coed y Mynydd	676	550	100	17	1,343
Coed y Gororau	597	2,163	494	136	3,390
Llanymddyfri	1,013	712	650	313	2,688
GB total	**250,744**	**93,765**	**110,943**	**16,688**	**472,170**

* The figures include estimates for non-responses.

Appendix 16. Estimated* total non-marketed arboricultural arisings for each Forest District.

F.C. Forest Districts	Non-marketed Stem wood (odt/year)	Non-marketed Branch wood (odt/year)	Non-marketed Wood chips (odt/year)	Non-marketed Foliage (odt/year)	Total Non-marketed Arisings (odt/year)
England	**167,862**	**62,354**	**66,173**	**5,815**	**302,204**
South East England	80,394	18,488	20,185	1,915	120,982
New Forest	2,680	182	4,608	0	7,470
Peninsula	2,487	2,310	1,623	34	6,454
Forest of Dean	4,366	3,394	2,996	567	11,323
West Midlands	2,825	2,278	174	63	5,340
Northants	12,619	1,595	7,976	118	22,308
East Anglia	13,430	7,060	4,640	100	25,230
Sherwood & Lincs	29,445	9,573	10,972	1,127	51,117
North West England	6,915	12,655	5,453	956	25,979
North York Moors	11,051	1,334	3,757	147	16,289
Kielder	1,650	3,485	3,789	788	9,712
Scotland	**4,214**	**3,074**	**4,391**	**769**	**12,448**
Scottish Borders	426	312	216	60	1,014
Ae	340	292	272	92	996
Galloway	170	146	136	46	498
Scottish Lowlands	1,833	857	2,398	3	5,091
Cowal & Trossachs	234	264	435	16	949
West Argyll	85	73	68	23	249
Lorne	43	37	34	11	125
Tay	223	323	197	150	893
Lochaber	57	0	6	0	63
Fort Augustus	43	37	34	11	125
Inverness	128	109	102	35	374
Dornoch	113	73	68	23	277
Moray	0	0	0	0	0
Buchan	127	110	102	69	408
Kincardine	392	441	323	230	1,386
Wales	**1,864**	**3,029**	**1,462**	**486**	**6,841**
Coed y Cymoed	784	703	711	325	2,523
Coed y Mynydd	61	77	100	0	238
Coed y Gororau	406	1,786	226	24	2,442
Llanymddyfri	613	463	425	137	1638
GB total	**173,940**	**68,457**	**72,026**	**7,070**	**321,493**
%	**69**	**73**	**65**	**42**	**68**

* The figures include estimates for non-responses.

Appendix 17. Total estimated* arboricultural arisings produced for England, Scotland and Wales by Forest District.

F.C. Forest Districts	Arboricultural arisings (odt/year)	Collected waste arisings (odt/year)	Arboricultural arisings + Collected waste arisings (odt/year	Utility works arisings (odt/year)	Total arisings (odt/year)
ENGLAND	**445,024**	**159,835**	**604,859**	**11,200**	**616,059**
South East England	159,869	46,821	206,690		
New Forest	7,711	3,845	11,556		
Peninsula	9,597	9,366	18,963		
Forest of Dean	28,485	5,976	34,461		
West Midlands	11,310	15,979	27,289		
Northants	26,835	10,612	37,447		
East Anglia	27,718	12,014	39,732		
Sherwood & Lincs	58,028	11,978	70,006		
North West England	39,445	27,393	66,838		
North York Moors	63,716	11,751	75,467		
Kielder	12,310	4,100	16,410		
SCOTLAND	**16,146**	**12,871**	**29,017**	**5,700**	**34,717**
Scottish Borders	1,976	324	2,300		
Ae	1,312	747	2,059		
Galloway	656	228	884		
Scottish Lowlands	5,885	7,850	13,735		
Cowal & Trossachs	1,402	348	1,750		
West Argyll	328	357	685		
Lorne	164		164		
Tay	1,352	1,295	2,647		
Lochaber	63		63		
Fort Augustus	167		167		
Inverness	501	845	1,346		
Dornoch	334		334		
Moray	0	344	344		
Buchan	501	134	635		
Kincardine	1,505	399	1,904		
WALES	**11,000**	**6,006**	**17,006**	**2,700**	**19,706**
Coed y Cymoed	3,579	2,017	5,596		
Coed y Mynydd	1,343	1,443	2,786		
Coed y Gororau	3,390	288	3,678		
Llanymddyfri	2,688	2,258	4,946		
GB total	**472,170**	**178,712**	**650,882**	**19,600**	**670,482**

* The figures include estimates for non-responses.

Appendix 18. Estimated* production of arboricultural arisings per habitant and year.

F.C. Forest Districts	Population	Arboricultural Arisings / hab (odkg)	Waste Collected Arisings / hab (odkg)	Total Arisings / hab (odkg)
England	**49,138,831**	**9.05**	**3.27**	**12.32**
South East England	16,014,561	9.99	2.92	12.91
New Forest	862,055	8.95	4.46	13.41
Peninsula	2,022,347	4.75	4.63	9.38
Forest of Dean	2,666,732	10.68	2.24	12.92
West Midlands	4,895,561	2.31	3.26	5.57
Northants	2,740,205	9.80	3.87	13.67
East Anglia	3,391,683	8.17	3.69	11.86
Sherwood & Lincs	3,625,864	16.00	3.30	19.30
North West England	6,729,800	5.86	4.07	9.93
North York Moors	4,313,388	14.77	2.72	17.49
Kielder	1,876,635	6.56	2.18	8.74
Wales	**2,903,085**	**3.79**	**2.07**	**5.86**
Coed y Cymoed	1,666,545	2.10	1.26	3.36
Coed y Mynydd	259,050	5.19	5.57	**10.76**
Coed y Gororau	542,903	6.25	0.53	6.78
Llanymddyfri	434,587	6.19	5.20	11.39
Scotland	**5,062,011**	**3.16**	**2.54**	**5.70**
GB total	**57,103,927**	**8.27**	**3.14**	**11.41**

* The figures include estimates for non-responses.

Appendix 19. Short rotation coppice planted from 1992 in England, Scotland and Wales under the Woodland Grant Scheme

Conservancy	Approved Payment Year	Area Paid (ha)
East England	1992/1993	1.48
	1993/1994	3.77
	1994/1995	3.48
	1995/1996	13.69
	1996/1997	1.67
	1997/1998	1.68
	1998/1999	0.10
	1999/2000	2.79
	2000/2001	0.56
	2001/2002	0.56
	2002/2003	1.64
	2003/2004	2.63
Total		**34.05**
East Midlands	1993/1994	7.06
	1994/1995	10.87
	1995/1996	2.80
	1996/1997	12.30
	1998/1999	15.65
	1999/2000	83.28
	2000/2001	230.93
Total		**362.89**
Grampian	1994/1995	0.50
	1998/1999	0.78
	1999/2000	7.19
	2000/2001	3.50
	2001/2002	3.33
Total		**15.30**
London Conservancy	1992/1993	2.64
	1994/1995	1.00
	1996/1997	3.80
	1997/1998	4.10
Total		**11.54**
Lothian And Borders	1994/1995	8.45
	1995/1996	2.25
	1996/1997	1.02
	1999/2000	2.00
	2002/2003	1.33
	2003/2004	2.60
Total		**17.65**
North East England	1993/1994	4.50
	1994/1995	0.43
	1995/1996	4.45
	1996/1997	2.10

	1997/1998	2.50
	1998/1999	9.71
	1999/2000	25.30
	2000/2001	3.30
Total		**52.29**
North Wales	1992/1993	0.20
	1993/1994	1.23
	1994/1995	0.20
	1995/1996	1.00
	1996/1997	3.04
	1997/1998	2.10
	1998/1999	0.10
	1999/2000	3.69
	2001/2002	0.64
	2002/2003	0.05
Total		**12.25**
North West England	1993/1994	0.20
	1995/1996	3.50
	1996/1997	3.44
	1997/1998	0.30
	1998/1999	1.02
	1999/2000	20.04
	2000/2001	0.51
	2001/2002	0.19
	2002/2003	0.30
Total		**29.50**
Perth	1996/1997	0.40
	1998/1999	3.00
Total		**3.40**
South East England	1992/1993	1.69
	1993/1994	6.80
	1994/1995	22.00
	1995/1996	9.01
	1996/1997	3.71
	1997/1998	2.29
	1998/1999	5.85
	1999/2000	10.68
	2000/2001	7.59
	2001/2002	4.20
	2002/2003	1.55
	2003/2004	1.23
Total		**76.60**
South Wales	1992/1993	0.98
	1993/1994	0.15
	1994/1995	0.50
	1995/1996	0.30
	1996/1997	2.05
	1997/1998	1.60
	1999/2000	1.80

	2000/2001	4.20
	2001/2002	2.60
	2002/2003	0.80
Total		**14.98**
South West England	1992/1993	2.85
	1993/1994	14.73
	1994/1995	25.73
	1995/1996	27.55
	1996/1997	10.36
	1997/1998	14.00
	1998/1999	4.55
	1999/2000	4.92
	2000/2001	7.66
	2001/2002	0.40
	2002/2003	3.53
	2003/2004	4.20
Total		**120.48**
South West Scotland	1993/1994	2.00
Total		**2.00**
Strathclyde	1994/1995	6.60
	1996/1997	20.80
	1997/1998	0.80
	1999/2000	3.19
	2000/2001	1.70
Total		**33.09**
West Midlands	1993/1994	2.9
	1994/1995	4.04
	1995/1996	5.11
	1996/1997	4.91
	1997/1998	0.10
	1998/1999	1.35
	1999/2000	9.07
	2000/2001	13.93
	2001/2002	0.50
	2002/2003	0.57
Total		**42.48**
Yorkshire And The Humber	1993/1994	1.32
	1994/1995	18.85
	1995/1996	0.30
	1996/1997	24.62
	1997/1998	64.93
	1998/1999	78.49
	1999/2000	212.67
	2000/2001	439.24
	2003/2004	0.53
Total		**840.95**
GB total		**1669.45**

Appendix 20. Short rotation coppice planted from 2001 in England under the Energy Crops Scheme (hectares)

Government Office Region	2001	2002	2003	Total
East of England	61.22	14.28	0	75.5
East Midlands	104.16	88.64	3.07	195.87
North East	0	6	0	6
West Midlands	6	0	0	6
Yorkshire and Humberside	61.81	60.12	0	121.93
North West	0	0	0	0
South West	0	0	0	0
South East	0	0	10.92	10.92
All regions	**233.19**	**169.04**	**13.99**	**416.22**
NOTE				
~ Figures based on claim forms received as at 09 June 2003.				
~ Currently all SRC is willow.				
~ Claim window is May to July so figures will increase during that period.				
~ ECS support means that the crops should already have a buyer.				

Appendix 21. Total short rotation coppice planted under the Woodland Grant Scheme and the Energy Crop Scheme since 1992 (by 18th June 2003) and estimated biomass production assuming an average annual production of 8 odt ha^{-1} y^{-1}.

Region/Country	Area Paid (ha)	Total Annual Production (odt y^{-1})
East England	109.95	880
East Midlands	558.76	4,470
London Conservancy	11.54	92
North East England	58.29	466
North West England	29.5	236
South East England	87.52	700
South West England	120.48	964
West Midlands	48.48	388
Yorkshire and the Humber	962.88	7,703
England Total	**1,987**	**15,899**
Grampian	15.3	122
South West Scotland	2	16
Strathclyde	33.09	265
Perth	3.4	27
Lothian and Borders	17.65	141
Scotland Total	**71.44**	**572**
North Wales	12.25	98
South Wales	14.98	120
Wales Total	**27.23**	**218**
GB total	**2,086**	**16,688.56**

Appendix 22 The area of traditional coppice (>.01ha) and contribution of small woodlands (<2ha).

Region	County	Area of Coppice > 0.1ha (ha)	Area of Woodland < 2ha (ha)	% of Total Woodland Area
England				
Greater London		193	296	4.8
South East	Berkshire	270	681	3.7
	Buckinghamshire	0	681	3.9
	East Sussex	2,739	1,125	3.8
	Hampshire	1,539	1,924	2.9
	Isle of Wight	8	59	1.3
	Kent	9,408	2,366	6.0
	Oxfordshire	0	1,362	7.5
	Surrey	917	770	2.0
	West Sussex	2,123	918	2.4
Region total		17,004	9,886	3.7
South West	Avon	0	458	5.5
	Cornwall	562	98	0.4
	Devon	204	2,473	3.7
	Dorset	382	657	2.3
	Gloucestershire	329	1,006	3.4
	Somerset	25	1,017	4.2
	Wiltshire	396	702	2.6
Region total		1,898	6,412	3.0
West Midlands	Hereford & Worcester	989	5,412	15.2
	Shropshire	91	3,347	11.4
	Staffordshire	0	2,914	13.8
	Warwickshire	0	1,340	14.3
	West Midlands	0	469	17.0
Region total		1,080	13,482	13.7
East of England	Bedfordshire	24	1,026	13.4
	Cambridgeshire	78	5,605	45.5
	Essex	529	4,034	20.7
	Hertfordshire	160	2,667	17.2
	Norfolk	503	8,583	16.3
	Suffolk	147	4,103	13.1
Region total		1,443	26,018	18.7
East Midlands	Derbyshire	21	3,779	19.4
	Leicestershire	31	1,566	16.2
	Lincolnshire	25	1,346	7.1
	Northamptonshire	84	2,114	14.6

	Nottinghamshire	5	1,356	7.8
Region total		166	10,162	12.7
Yorkshire & The Humber	Humberside	265	274	3.0
	North Yorkshire	64	1,271	2.1
	South Yorkshire	106	254	2.2
	West Yorkshire	57	155	1.5
Region total		492	1,954	2.1
North East	Cleveland	0	44	1.2
	Durham	0	436	2.8
	Northumberland	0	1,337	1.7
	Tyne and Wear	0	196	6.8
Region total		0	2,013	2.0
North West	Cheshire	25	895	8.7
	Cumbria	82	2,829	4.4
	Greater Manchester	0	366	7.8
	Lancashire	0	674	4.8
	Merseyside	0	73	2.9
Region total		107	4,838	5.0
England total		**22,384**	**75,063**	**6.8**
Scotland				
	Borders	52	6,296	7.2
	Central	0	2,254	4.2
	Dumfries and Galloway	0	1,709	1.0
	Fife	55	1,683	11.0
	Grampian	0	3,404	2.2
	Highland	155	1,604	0.5
	Lothian	0	2,008	11.2
	Strathclyde	855	3,527	1.1
	Tayside	66	6,214	6.0
	Western Isles	0	0	0.0
	Orkney	0	0	0.0
	Shetland	0	0	0.0
Scotland total		**1,183**	**28,698**	**2.2**
Wales				
	Gwynedd	0	1,775	3.7
	Clwyd	0	425	1.8
	Dyfed	0	4,329	5.6
	Powys	6	6,888	9.2
	Glamorgan	253	2,349	5.6
	Gwent	229	968	5.1
Wales total		**488**	**16,734**	**5.8**

Appendix 23 . Municipal Wood Waste Arisings (WRAP 2002)

Country	Forest District	Woody waste CA (tonnes)
England total		**331308**
	Peninsular	18371
	New Forest	7690
	South East England	93642
	East Anglia	36039
	Northants	21224
	Forest of Dean	11951
	West Midlands	31958
	Sherwood and Lincs	23956
	North West Lincoln	54786
	North York Moor	23502
	Kielder	8189
Wales total		**12010**
	Coed y Cymoed	4034
	Llanymddyfri	2885
	Coed y Mynydd	576
	Coed y Gororau	4515
Scotland total		**25086**
	Scottish Borders	648
	Ae	845
	Galloway	455
	Scottish Lowland	15699
	Cowal and Trossachs	695
	West Argyll	713
	Lorne	-
	Tay	2589
	Lochaber	-
	Fort Augstus	-
	Inverness	1689
	Moray	688
	Kincardine	797
	Buchan	268
GB total		**368404**