Section 8

Survey Methods for Kyoto Protocol Monitoring and Verification of UK Forest Carbon Stocks

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8. Survey Methods for Kyoto Protocol Monitoring and Verification of UK Forest Carbon Stocks

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8.1. Summary

This report details progress that has been made in the development of inventory-based methods for Kyoto Protocol monitoring of forestry based LULUCF activities. A detailed methodology is given for estimating carbon stocks associated with British forests, which are fully compatible with Landcover Map 2000. These estimates include soil carbon stocks and carbon stocks in standing timber and associated woodland components. The estimates are primarily based on data recorded in the National Inventory of Woodland and Trees (NIWT) and the Forest Enterprise sub-compartment data-base. The current consultation over protocol development relevant to assessing woodland carbon stocks is also described, together with the implications for reporting carbon stocks and stock changes in woodland.

8.2. Introduction

The Kyoto Protocol (UNFCCC, 1998) contains a number of stipulations concerning the reporting by participating countries of net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities. The Protocol places restrictions on precisely what sources and sinks should be counted as part of a national greenhouse gas balance (notably in terms of any forestry activities initiated before 1990). However there is an implicit requirement for participating countries to develop the capability to periodically monitor and report carbon stocks and stock changes associated with national forests. In particular, countries are required to provide data to establish the level of national forest carbon stocks in 1990 and to enable an estimate to be made of changes in carbon stocks in subsequent years. The Protocol further stipulates that all such monitoring must be undertaken in a transparent and verifiable manner.

The purpose of this report is to present a preliminary methodology that may be used for the assessment of relevant carbon stocks and stock changes in the UK over a five-year cycle to sufficient accuracy and cost-efficiency. Based on this evaluation, a strategy will be developed for the evolution of existing systems to meet requirements for reporting carbon stocks and stock changes. Opportunities for adding value to existing systems and monitoring networks through adaptation or extension are identified, including scope for integration and rationalisation. Emphasis is placed on a nested design in which national-scale surveys are used to provide input data to carbon stock/change models, while smaller numbers of research plots are measured more intensively to provide data for validation of models and verification of estimates.

8.3. The National Inventory of Woodland and Trees (NIWT)

8.3.1. General description of NIWT

The Forestry Commission has carried out six national woodland inventories for Britain since 1919. The sixth national inventory, the National Inventory of Woodland and Trees (NIWT1), was started with a pilot survey of Grampian in 1994, and the fieldwork in Scotland was completed in early 1997, and by late 1999 in England and Wales. These GB national inventories have been carried out at roughly 10-15 year intervals, and have typically taken 4-5 years to complete. With successive inventories, the emphasis has moved from being purely an assessment of the timber resources to take in wider environmental aspects.

The proposed aim of the next round (NIWT2) is to provide up-to-date information on the extent, size and composition of our woodlands. In particular, the aim is to provide an accurate assessment of woodland area, and to provide estimates of a set of variables. The survey data will provide information for:

- decisions on land use and woodland expansion;
- forecasting timber production;
- targeting advice and grant aid;
- assessing woodlands as a wildlife and conservation resource;
- studies on biomass production and carbon storage;
- monitoring the sustainability of forest management, and contributing to the monitoring of sustainable development of land use;
- other more specialised woodland surveys.

NIWT2 is designed to give information at regional, national and GB levels. The vision for NIWT2 is that it should provide a GB-wide survey collecting a core set of variables that will satisfy UK indicators and international reporting and, that for most national needs, it should be flexible enough to respond to further requirements. NIWT1 was envisaged as the first of a rolling programme of national inventories, differing from the Forestry Commission's previous practice of periodic surveys by starting the next round soon after completion of the current survey. However, it was still a 'stand-alone' survey. NIWT2 is proposed as a continuous, rolling programme. Once the first cycle is complete the system will provide annual inventory updates in all countries every year. Available resources can dictate the length of the cycle. Many countries have already adopted this system, including USA, Canada, and all the Nordic countries, while France, Italy and some other European countries are currently converting to the system.

The framework within the more detailed measurement protocols proposed for NIWT2 operate (see Smith, 2004) is as follows:

- the main survey should update the digital woodland map, and use it as the framework within which to survey 1% of woodland area, using 1 hectare sample plots;
- sample plots should be selected using a simple grid across the whole country;
- a proportion of plots should be visited annually, dependant on the cycle, e.g. 20% per annum for a 5-year cycle;
- a supplementary sample survey of small woods and trees should give information on woodland outside the mapped area.

8.3.2. Current status

The current National Inventory of Woodland and Trees (NIWT2) is planned for 2004-2008, with an ongoing rolling programme to continue. A pilot exercise was carried out during the summer of 2003, to provide indications of costs and resources required for the full programme of measurements, including options for additional measurements. These additional measurements have an important bearing on the ability to upscale to provide national estimates of carbon stocks and stock changes. Progress has therefore been limited, as the carbon stock pilot study to be undertaken in this project can only proceed within the wider framework of measurement protocols that are adopted in NIWT2.

The current position is that the precise format of NIWT2 is out to consultation with the national Forestry Commission offices and associated stakeholders. It is intended that the position in all three countries is finalised at meetings in June 2004, with the consultation planned to be completed by the end of July 2004. A number of points that are highly relevant to the future use of NIWT2 for carbon stock and stock changes associated with LULUCF are included within the consultation, and discussed below (Smith, 2004).

<u>Canopy cover:</u> It is proposed that the FRA/FAO woodland definitions for canopy cover (10%) should not be adopted, but that the current UK definition of 20% woodland cover be maintained as a threshold. The 'small woods and trees' survey could be used to provide estimates of attributes in areas for which canopy cover is below the threshold.

Alternative: use 10% canopy cover.

<u>Minimum woodland size:</u> The FRA/FAO minimum woodland size (0.5 ha) could be adopted as a threshold in the main survey, extending the woodland map from the current minimum of 2 ha. A less intensive 'small woods and trees' survey (based largely on photo-interpretation) could provide a more general estimate of smaller woods.

Alternative: maintain mapping to 2 ha, with estimates between 0.1 ha and 2 ha.

<u>Woodland map:</u> Propose to use digital, ortho-rectified aerial photos to update the digital woodland map - if available. It is also proposed to adjust polygon boundaries to OS MasterMap, where appropriate (potentially giving better fit with other data-sets).

It has been assumed that the FC will acquire a GB national digital photography data-set. This has not yet happened, and will potentially delay the inventory if not acquired.

Alternative: continue to update extent of woodland using existing map, but ignore internal changes and losses.

<u>Start date:</u> It is proposed to start in 2004. It is already 15 years since the aerial photography cover, which formed the basis of the current Scottish woodland map, was flown, and up to 10 years in England and Wales. Although new woodland has been added to the map, all internal details are as in the original maps (1988 in Scotland). Thus, there has been no recording of felling, planting of prepared ground or growth of young plantations.

Alternative: start later.

<u>Survey cycle:</u> Rather than conduct a periodic survey, it is proposed that a continuous national woodland inventory should be adopted. The cycle could be between 5 and 10 years depending on funding, but 5 years is proposed, i.e. completing field work for the first cycle in 2008. Britain's

first 6 national inventories were discrete surveys carried out 10-15 years apart. The most significant difference between a ‘discrete’ and a 'continuous' inventory is that the latter is designed to progress annually and, with a 5-year cycle, then any 5-year period will contain a full national inventory. One advantage is that after the first cycle, each country is in effect completing a national inventory every year, and the last 5 years worth of data can be used to produce 'fresh' national inventory results.

Alternatives: discrete or continuous cycle, selection of length of cycle.

Geographic progression: It is proposed that a proportion of each country should be surveyed each year - e.g. 20% if a 5-year cycle was adopted. Furthermore, it is proposed that that 20% should be spread across the whole country. A disadvantage will be that all regions must wait until the end of the first cycle to get full results, but an advantage is that national up-dates can be estimated annually.

Alternative: progress region by region in each country, and/or progress country by country.

Sample size: It is proposed that the main inventory should sample 1% of the forest area, using 1 hectare sample plots.

Alternative: an option could be to expand sample size for areas of environmental interest (e.g. native woodlands, woodland subject to Habitat Action Plans), so that sampling is greater than 1% in these areas, enabling better estimates to be produced for more aspects. This is an option, which would not be funded within the existing budget, and has implications for both field and analysis resources.

Sample plot selection: Rather than stratify woodlands by woodland size and cluster the 1 ha sample plots, as used in the recent national inventory, it is proposed to adopt a 1 km by 1 km grid, with 1 ha within each grid square being selected as a sample plot where it lands on woodland. This should not increase travel times significantly, but will enable better co-ordination and integration with other monitoring initiatives, e.g. Forest Condition and the possible EU initiatives within 'Forest Focus'. Most countries which have adopted a continuous rolling national forest inventory also have a grid system.

Alternative: adopt system used in recent national inventory, but improve clustering.

Permanent plots: To increase the effective monitoring of change in the future it is proposed that up to 20% of the sample plots should be permanent, i.e. should be revisited in future cycles. Previous inventories have never revisited the same plots, and hence have had no good benchmarks to show if changes were 'real' or attributable to changes in methodology.

Alternative: all plots 'temporary'.

Information collected in the field: To satisfy current and future demands for data - particularly the recently published 'UK Indicators of Sustainable Forestry’ - the aim is to expand the range of data collected on field visits, incorporating more information about environmental aspects, native woodlands, management and potential timber quality, with some variation in extra data depending on nature of woodland.

Alternatives: A number of additional variables could be included; proritisation would be necessary.

8.3.3. Prioritisation of addition measurements

A protocol which allows, on average, 2 sample squares to be assessed per day would allow NIWT2 to be carried out within the baseline funding detailed below. Using the Pilot Protocol took 4.7 hours per square, excluding travel time. Some items from the Pilot would therefore need to be dropped unless extra funding was available. Digging soil pits takes around 0.5 hours per plot, and measuring trees in the sub-plots slightly longer. These variables have been presented as 'optional' in the summary list. Preliminary costings suggest that the mapping, core fieldwork and data handling will be around £500,000 per annum. 'Optional' extra data would add in the region of the following:

- £20-£40K per annum for monitoring woodland loss and damage
- £80K per annum for adding extra samples to monitor native woodland
- £80K per annum to add soil assessment
- £90K per annum for collecting mensurational data

Timber quality assessment and increased information on native woodlands are now considered necessary, and should be incorporated into the survey at no extra cost.

The information proposed to be collected on native woodlands would give estimates of woodland area for each native woodland HAP type, plus a full breakdown of species, age, etc., and could be cross-analysed with all other variables collected. There could also be a breakdown of each HAP type by condition. There will, however, be no map of native woodland.

8.3.4. Preliminary assessment of protocols to be implemented in the two pilot areas

A derivation of carbon stocks and stock changes from data collected as part of NIWT2 can only be satisfactorily achieved if mensuration data are collected as part of the core protocol. Soils information are not as essential as mensuration data, although they would provide a valuable verification step and improve the uncertainty estimate associate with soil carbon stocks. Whatever the outcome of the NIWT2 consultation process, both mensuration and soil data will be collected in the two pilot areas.

The timing of the first measurements within NIWT2 will not compromise the proposed work within the two pilot areas, assuming that this work commences in the summer of 2004 or 2005. However, if a regionally based rolling programme is implemented that does not include the two pilot areas in the initial phases, the work proposed in this contract will need to be undertaken as a separate exercise. Furthermore, if the methodology for estimating carbon stocks (and thus stock changes) are applied on a national basis in the implementation phase of the 2008-12 LULUCF reporting under the Kyoto Protocol, the precise sampling strategy could have important implications for the associated calculations.

The last National Inventory was based upon analysis of aerial photography (together with ground-truthing) from 1988 (Scotland) and approximately 5-years later for England and Wales. The Forestry Commission is negotiating access to more recent data through the Ordnance Survey. Scotland is due to be overflown during the summer of 2004 on behalf of getmapping Plc, while England and Wales have been re-surveyed between 1998 and the present. Further updates are planned, and a rolling three year update contract is currently being negotiated. An alternative data source is a GB-wide ortho-rectified radar data-set (Nextmap – getmapping Plc and Intermap technologies) from 2002/3, which would be used if more recent aerial photographs are not available. It is thus planned to only use maps and photographs dated post-2000, with updates to woodland areas made possible beyond this time through FC Grants and Licenses information. NIWT2 will thus include 'internal' woodland changes, as well as changes to external boundaries

8.3.5. Methodology for deriving carbon stocks in NIWT sample squares

For production woodland, carbon stocks of standing timber will be assessed from conventional yield models underlying BSORT, using the abbreviated mensuration measurements included within the NIWT2 pilot area protocols as input. Generic models for non-productive woodland are also available, as described elsewhere. Deadwood assessments within the NIWT2 protocol will provide an assessment of carbon stocks associated with litter, but foliage and small diameter branchwood litter will not be accounted for outside modelled estimates from BSORT based on allometric relationships, as described elsewhere in this report. Soil carbon will be estimated using the same methodology as described for SCDB data-sets, and using the 'detailed soil-type' classification given in Horne and Whitlock (1984).

Estimates of carbon stocks will only be made for the central element of the NIWT2 squares where mensuration and soil data are available. These estimates will thus not be comparable with the wider assessments made within NIWT2, and this should be acknowledged in any interpretation of the results. However, scope remains to extend the analysis within the pilot areas to provide a qualitative comparison of woodland carbon stocks based solely on the central elements and one based on all elements recorded within the 1 ha sample square. This assessment would contribute to the verification and uncertainty analyses described elsewhere.

8.4. Harmonisation of LCM and NIWT

Estimates of carbon stocks and stock changes associated with woodland should be compatible with those for other land uses, while the development and acceptance of a single forest cover map would benefit a wide range of research and policy development programmes. Significant discrepancies exist between estimates of woodland cover derived from the two major land-use maps, NIWT and LCM (Hall *et al*., 2003; Matthews and Broadmeadow, 2003). These discrepancies arise as a result of differences in methodology, classification, scale, interpretation and technology. The proposed re-alignment of NIWT2 polygons to Mastermap will reduce some of the significant errors between NIWT and, for example, the Ancient Woodland Inventory reported by Griffiths *et al*. (2003). Furthermore, more recent aerial photography will enable updated internal boundaries to be mapped as described previously. However, some of the discrepancies cannot be reconciled within the timeframe of this contract. Differences in interpretation between satellite and aerial photography images, including heathland often being assessed as woodland and young trees not being identified from satellite imagery, will remain. However, certainly in the case of FE managed woodland, but also some private woodland, the meta-data available through either the SCDB or from FC Grants and Licenses is likely to result in NIWT2 providing a better estimate of woodland cover and will be used as the definitive data-set since the protocol has been developed specifically to assess woodland cover, rather than distinguishing between a much larger range of land-uses.

8.5. The sub-compartment data-base

8.5.1. Data holding

The sub-compartment database (SCDB) was established in the 1980s to provide information relevant to management of Forestry Commission woodland. The data are arranged by Forest District and updated on an annual basis. The sub-compartment is defined as the smallest management unit, with a minimum area of 0.5 ha. There may be no permanent physical boundaries, but the sub-compartment delineates a specific land-use or crop type. Three types of data are stored – meta-data, mandatory data (for all crops) and optional data which provide additional site information. The data held within the SCDB are summarised in Table 8-1.

Table 8-1 Data held within the sub-compartment database (after Horne and Whitlock, 1984).

Meta-data	Mandatory data	Optional data
Forest number	Land-use and crop type	Management status
Block	Storey (main or secondary)	Main soil type
Compartment	Species	Lithology
Sub-compartment	Planting year	Altitude
Component (to 0.1 ha)	Yield class	Terrain type
	Production forest area	Windthrow Hazard class
	Unproductive forest area	
	Legal status	
	Conservation constraint	

8.6. Estimating soil carbon stocks

8.6.1. Derivation of soil carbon stocks in Forestry Commission woodland

The SCDB contains, as an optional field, soil type. Either general or detailed codes (Table 8-2) are given depending the level of soil survey, with 31% and 35% coverage of the FE estate available for the two levels of detail, respectively. Individual soils, classified according to the Forestry Commission soil classification system (Pyatt, 1982; Kennedy, 2002), included within each general or detailed soil grouping are also given.

For both general and detailed soil types, the carbon content to a depth of 1 m, or to bedrock, whichever is the shallower will be calculated from carbon content and bulk density measurements from representative soil profiles published in the five regional soil survey regional Bulletins for England and Wales (Findlay *et al*., 1984; Hodge *et al*., 1984; Jarvis *et al*., 1984a; Jarvis *et al*., 1984b; Ragg *et al*., 1984; Rudeforth *et al*., 1984). A similar process will be used to derive soil carbon densities in Scotland. If appropriate, regional variation in carbon densities for both general and detailed soil types will be accounted for by applying regional carbon densities for each soil type, according to the Regional Soil Survey Bulletins (Northern England, Wales, Midland and Western England, Eastern England, South West England, South east England, South Scotland, North Scotland).

The carbon densities derived using the above process will be applied to those sub-compartments within the SCDB for which soils information, either general or detailed, is available (Table 8-3). Although 66% of sub-compartments do have associated soils information, some FE Forest

Districts have a paucity of relevant data, including Inverness (23%), Kielder (20%) and Sherwood and Lincolnshire (20%). Of the two pilot areas that have been selected on a preliminary basis, north Hampshire/Surrey has good soil data (81% detailed and only 1% unclassified). In contrast, data coverage for Tay is poor, with information available for only 60% of the FE woodland and of that, less than half comprises detailed soil types.

Table 8-2 Soil classification within the FE SCDB (Horne and Whitlock, 1984).

General soil type	Detailed soil type	FC soil map classification
Brown earths	Brown earth Podzolic brown earth Base rich brown earth	1, 1d, 1g, 1u, 1v 1z 1b, 12t
Podzols	Typical podzol Peaty podzol	3, 3c, 3g, 3l, 3x 3p
Ironpan soils	Intergrade ironpan soil Ironpan soil Peaty ironpan soil Podzolic ironpan with induration Podzolic ironpan soil	4b 4, 4g, 4x 4p, 4pg 4zx 4z
Peaty gleys	Peaty gley – clay texture Peaty gley – loamy texture Peaty gley with induration Peaty ground-water gley	6, 6f, 6p, 6z 6l, 6pl 6xf, 6zx 5p
Gley soils	Ground-water gley Valley bottom complex Surface-water gley – clay texture Surface-water gley – loamy texture Surface-water gley with induration	5, 5b, 5z VC 7, 7b, 7f, 7h, 7I, 7z 7l, 7lf, 7lh, 7li 7fx, 7zx
Flushed peat bogs	Juncus bog – moderate nutrients Molinia bog – moderate nutrients Molinia bog – poor nutrients	8a, 8b, 8c, 8d 9a, 9b, 9c 9d, 9e
Unflushed peat bogs	Non-flushed blanket bog Sphagnum bog	11a, 11b, 11c, 11d, 14 10a, 10b, 14w
Littoral/skeletal soils	Well drained littoral soil Poorly drained littoral soil Skeletal soil, freely drained Skeletal soil, poorly drained	15d, 15e, 15i 15g, 15w 13b, 13c, 13h, 13r, 13s, 13z, 15s 13g, 13h, 13p
Calcareous soils	Rendzina Calcareous brown earth Calcareous gley	12a 12b 7k

8.6.2. Extrapolation to private woodland

Soils information is not available for private woodland. The distribution of private woodland will be broken down on a regional basis corresponding to FE forest districts, with broadleaf and mixed woodland accounted for separately. For each forest district, an assumption will be made that soil type distribution is identical in FE and private woodland, including the distinction between broadleaf and conifer woodland. This assumption will be tested using soils information collected as part of NIWT2 in the two pilot areas and, also, within the network of plots aligned to the transnational 16 x 16 km grid.

Table 8-3 Availability of general and detailed soil type data within the SCDB for individual FE Forest Districts.

	Area			% data holding		
	General	Detailed	Unclassified	General	Detailed	Unclassified
Ae	6689	23930	788	21	76	3
Buchan	6074	14089	1755	28	64	8
Cowal & Trossachs	21390	5881	29728	38	10	52
Dornoch	4052	20241	41157	6	31	63
Fort Augustus	16451	2913	40830	27	5	68
Galloway	67245	16347	13379	69	17	14
Inverness	1952	6144	27312	6	17	77
Kincardine	761	12837	760	5	89	5
Lochaber	21952	4	22055	50	0	50
Lorne	22464	409	25489	46	1	53
Moray	37	22046	609	0	97	3
Scottish Borders	9492	14795	2134	36	56	8
Scottish Lowlands	13757	7120	17325	36	19	45
Tay	13088	9510	15325	35	25	40
West Argyll	44915	9836	9682	70	15	15
East Anglia	104	23815	1057	0	95	4
Forest of Dean	11267	3586	1261	70	22	8
Kielder	8456	6729	59849	11	9	80
New Forest	782	15640	18647	2	45	53
Northwest England	4367	8846	3631	26	53	22
North York Moors	7584	12635	1249	35	59	6
Northants	20	4568	2937	0	61	39
Peninsula	7854	3720	4405	49	23	28
Sherwood & Lincs	2458	139	10432	19	1	80
Southeast England	4000	18051	299	18	81	1
West Midlands	875	6733	5015	7	53	40
Coed y Cymoedd	1914	25913	2684	6	85	9
Coed y Gororau	9686	10186	2931	42	45	13
Coed y Mynydd	7905	29397	1246	21	76	3
Llanymddyfri	6736	28566	838	19	79	2
Scotland	250319	166103	248328	38	25	37
England	47768	104463	108783	18	40	42
Wales	26241	94062	7699	21	73	6
GB	**324328**	**364629**	**364811**	**31**	**35**	**35**

8.7. Adapting the production forecast to upscale estimates of standing forest carbon stocks

Data held within the SCDB provide estimates of standing volume in stemwood through the relatively simple process of applying empirical growth and yield models (eg Edwards and Christie, 1981). The biomass associated with non-stemwood must then be calculated by applying expansion coefficients, with the final step in the process, detailed below, being the conversion to standing carbon on the basis of a 50% C content (Matthews, 1993). These estimates are arrived at using the model BSORT (Matthews and Broadmeadow, 2003) which, although not described here, is also capable of providing information on home-grown stocks associated with the harvested wood products carbon pool.

8.7.1. Tree biomass

A full description of the methods used to extrapolate from a knowledge of species, current volume of 7+ cm diameter stems and yield class to biomass of all other tree components is given in McKay (2003). Only the basic principles are given here, outlined as three separate processes:

- estimating tree components from basic stand data;
- integrating data into a production forecast system;
- forecasting production of all biomass components for FC woodlands.

8.7.2. Estimating tree components from basic stand data

Assessments of volume per hectare in standing tree stems are readily available from records maintained on Forestry Commission permanent sample plots and also in published yield models. Stem volume estimates can be converted to biomass (in units of oven dry tonnes per hectare) by multiplying by the appropriate average nominal specific gravity for the species of wood in question.

For tree components other than the stem, species-specific equations have been developed to enable biomass to be computed from variables that are more readily available. This required a comprehensive review of data on biomass allocation to tree parts other than stems, including relevant data from the scientific literature and Forestry Commission sources. A further opportunity to validate these allometric relationships will arise during routine thinning operations scheduled for the UNECE/ICP-Forests Level II network during the winter of 2004-5.

The bulk of data on the biomass of different tree components has been collected on individual trees rather than for whole stands, and therefore a system has been devised that permits the upscaling of biomass estimates from tree to stand scale. The methodology adopted consists of three stages as follows.

In the first stage, species-specific allometric relationships were constructed for estimating the root, branch and foliage mass of individual trees from standard mensurational variables, i.e. tree diameter at breast height (dbh: 1.3 m) and/or height. Details of these allometric relationships are given in a later section, with the individual equations given in Table 8-4 to Table 8-6. For some groups of species it was impossible to distinguish significant differences in allometry and a common relationship was assumed. For certain tree species, generally minor species in terms of British forestry, there were insufficient data for the calibration of a reliable relationship. In these cases it was assumed that allometry followed the pattern characterised for another species or species group. The assignment of this ‘nearest available’ result was based on:

- the range of alternative results available;
- dendrological considerations;
- knowledge of growth characteristics of different tree species in Britain (Hamilton and Christie, 1971; Hamilton, 1975).

The second stage involved 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).

In the third stage, existing computer-based yield models were integrated with the tree size-class distribution models and allometric relationships to generate stand-scale biomass estimates. The computer code comprising this integrated suite of models and equations formed a major module of the program designed to estimate the biomass per hectare in specified components of trees. The integration of sub-models and equations within this model, BSORT, is illustrated in Figure 8-1

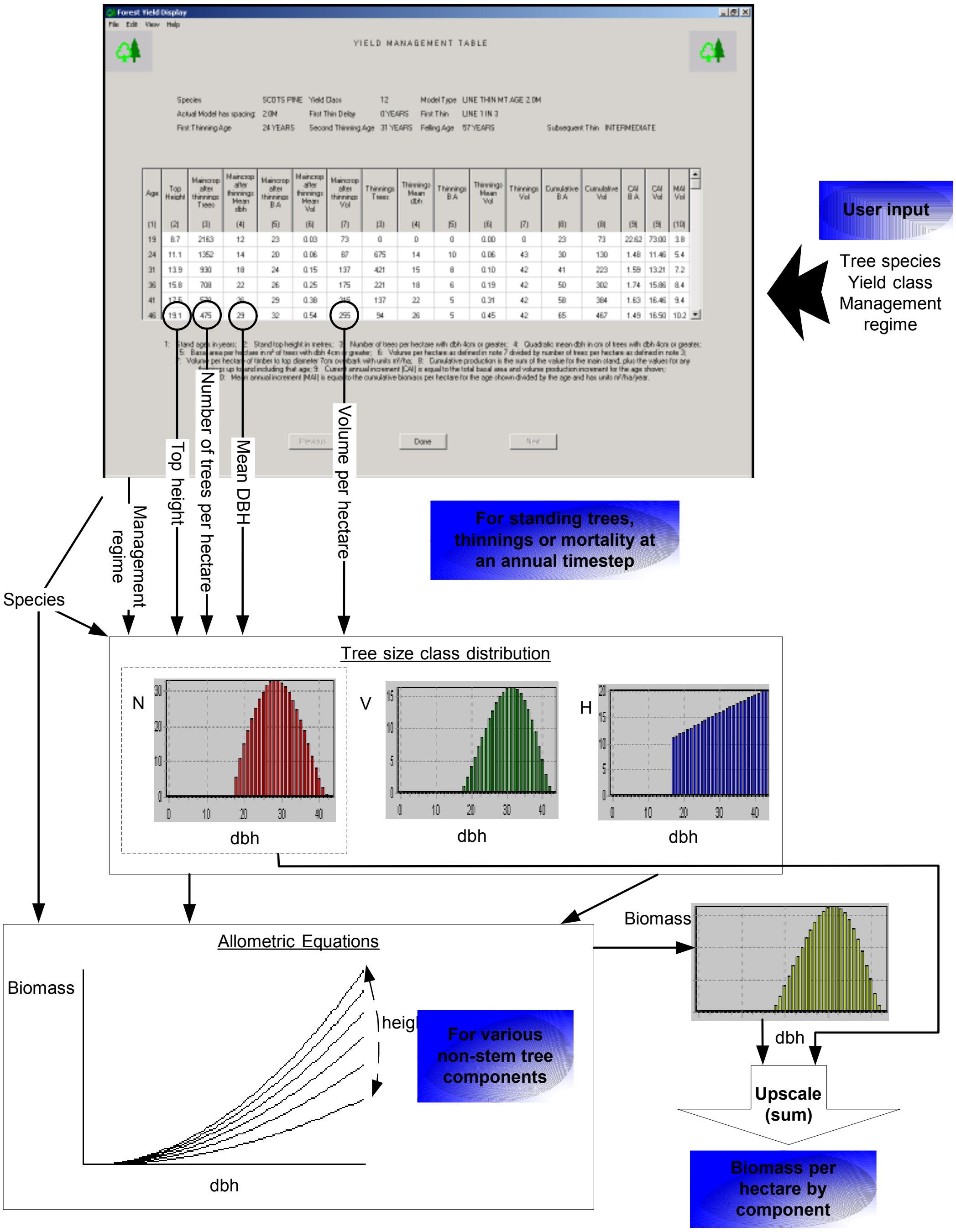

Figure 8-1 Illustration of structure of main module of BSORT computer program for estimating biomass of tree components.

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

This section 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. The bulk of the data for conifers came from the Forest Research 'treepull' data set. Additional Sitka spruce data were obtained from Burger (1953), Carey and O'Brien (1979), Bormann (1990) and Bergez (1988). A sequence of papers authored 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 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, as detailed below.

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.

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.

Carey and O'Brien: All information was available.

Bormann: No root biomass information was available. Stem biomass and branch mass were calculated as for Bunce. Based on expert judgement, an assumption was made that the estimates of above-ground biomass referred to woody biomass only.

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

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, 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 biomass, 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 8-4. 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. Further data are now available from measurements made within the the UNECE/ICP Forests Intensive Forest Health Monitoring Network.

Individual trees for which no estimates of aboveground biomass, crown biomass, or aboveground woody biomass were available 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. Details of the allometric equations finally selected and of associated parameter estimates are provided in Table 8-4 (leaf biomass), Table 8-5 (crown biomass) and Table 8-6 (root biomass). Estimates of woody branch biomass may be computed as the difference between crown biomass and leaf biomass.

Table 8-4 Summary of leaf biomass models and parameter estimates.

Generic woodland type	Leaf biomass model
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 8-5 Summary of crown biomass models and parameter estimates.

Species	Function (<= 7 cm dbh)	Parameters (<=7 cm dbh)	Function (>7 cm dbh)	Parameters (>7 cm 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 8-6 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

8.7.4. Developing a production forecast system

This facility within BSORT was implemented by integrating the program with an existing forest products assortment forecasting program, ASORT. The ASORT program was originally developed to provide forest managers with estimates of the potential volume of products of different specifications available from given forest stands (Rollinson and Gay, 1983). In order carry out such a forecast, ASORT requires as input data:

- the numbers of trees and volume per hectare in the stand of interest;
- the distribution of tree size classes (in terms of dbh and height) in the stand of interest;
- specifications for the products to be cut from the stand (in terms of maximum and minimum top/bottom diameters and minimum and maximum product lengths, with or without length increments, or fixed product lengths, as appropriate);

Sub-models of the BSORT program generate the stand and tree size-class information required as input data to ASORT and therefore it is possible for BSORT to call ASORT effectively as a subroutine, passing these data as arguments (Figure 8-2). It is also possible to define a simple specification for the different stem wood products in terms of minimum top diameters. To permit thorough testing of the completed BSORT model, a stand-alone user interface was developed. This could be used to quickly enter values for species, yield class, management regime, stand age and other relevant input variables which were then passed to BSORT. The interface could also be used to display outputs from BSORT for checking. A screenshot of the BSORT user interface with example input data and results is shown in Figure 8-3.

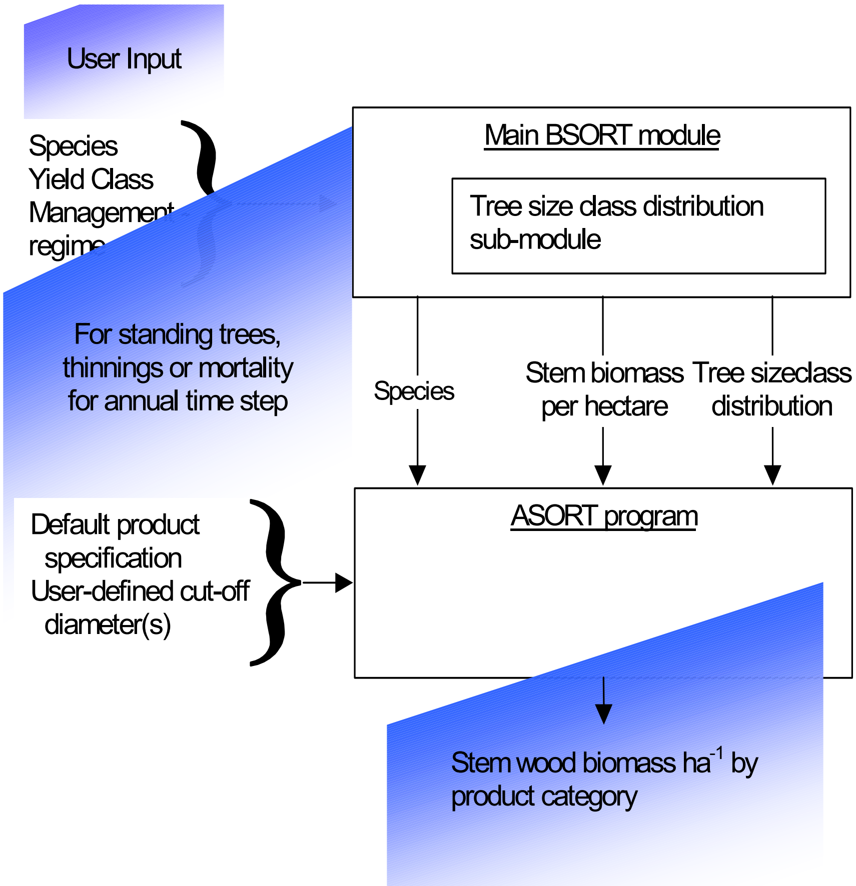

Figure 8-2. Illustration of interface between main BSORT module and ASORT computer program for forecasting biomass in stemwood components.

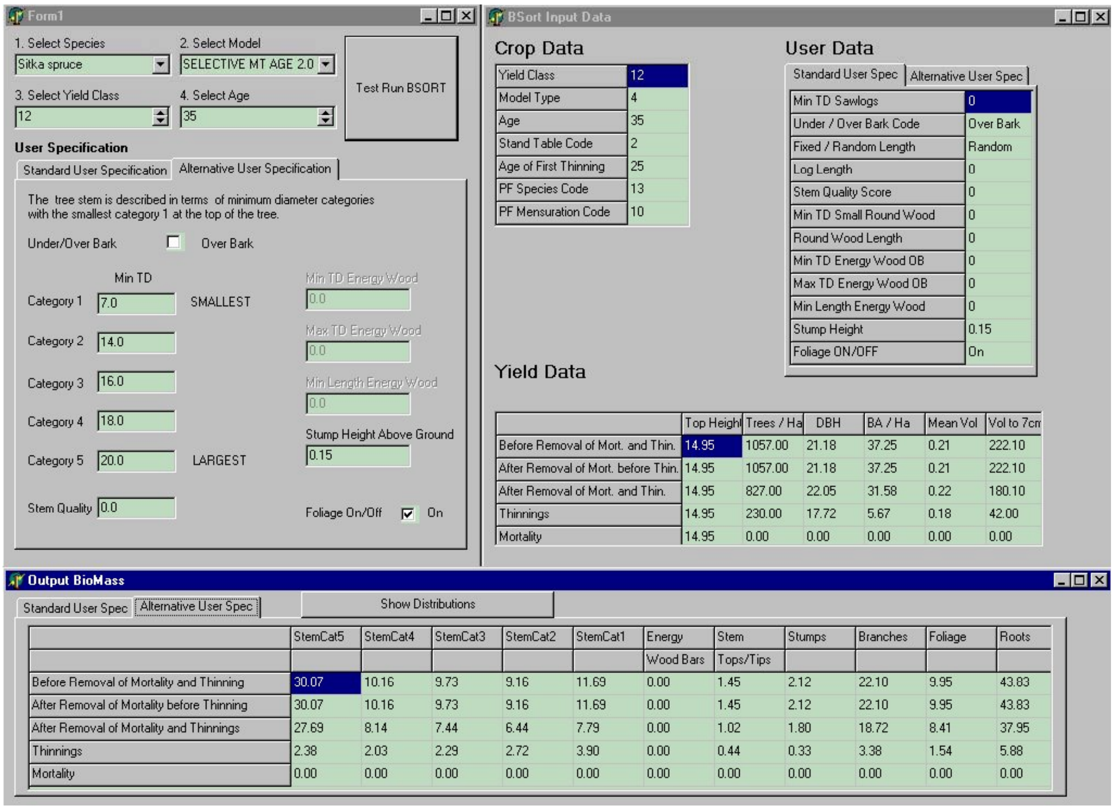

Figure 8-3. Screenshot of the BSORT model showing an example of model inputs and predictions

8.7.5. Forecasting production of all biomass components for Forestry Commission woodlands

The new version of the FC Production Forecast program in conjunction with BSORT can be run to give predictions of biomass for tree components for each of 30 Forest Districts using data on forest cover, species, yield class, age and Forest Design Plans from the sub-compartment database that relate to the district. One significant difference from the standard Forest Enterprise forecast is that only land classified as high forest or windblown is included in the standard published production forecasts for FE; within these categories, land for which timber production is not the main management aim is removed and regarded as non-forecastable. The proposed methodology will assess all land that has a tree species (including arboreta and other such stand types), therefore indicating the total carbon stocks associated with Forestry Commission land. For these (unproductive or non-high forest) stands, all data used for forecasting timber production has already been surveyed and is present in the SCDB.

The combined Production Forecast/BSORT system gives estimates of quantities of biomass on an oven-dry weight basis for the following individual elements:

- the stem (as divided up according to cut-off diameters that can be specified by the user);
- stem tips (i.e. material between the specified lowest cut-off diameter on the stem and the tip the main stem);
- woody branches;
- foliage;
- tree stumps;
- the woody root system.

8.7.6. Forecasting production of all biomass components for private sector woodlands

The procedure is generally similar to that outlined above except that:

- the private sector forecasting model has slightly different assumptions (see McKay, 2003);
- the private sector uses felling plans as opposed to Forest Design Plans.

Detailed information on planting year, species, management or productivity class are not available for private woodland, with the exception of NIWT sample squares. Information collected in NIWT2 therefore has to form the basis of any carbon inventory. A number of assumptions have to be made for this process to be implemented:

- for production woodland, the distribution of yield class and soil type for a given species are identical for FE-managed and private woodland; this assumption will be applied at a regional level, using the FE Forest District as the geographical unit;
- for unproductive woodland, common growth functions will be applied across FE-managed and private woodland;
- for both productive and unproductive woodland, any difference in approaches to management has no impact on productivity, form or soil and biomass carbon stocks;

It may be possible to test these assumptions during the course of the two pilot studies. However, the maximum number of sample points in each 40 x 40 km pilot area is 1600, which is likely to be reduced to ~280 and 200 for north Hampshire and Tayside, respectively, on account of their woodland cover of 17.7% and 12.9%. This may mean that statistically valid testing of these assumptions is only possible for dominant species in each of the pilot areas.

8.8. Overview of carbon inventory verification

The inventory methodology described here is primarily based upon two data-sources – the sub-compartment database and the National Inventory of Woodland and Trees. These two data-sets, together with Landcover map 2000 provide the extensive network described in Matthews and Broadmeadow (2003) and shown as Figure 8-4. The remaining three levels of network provide calibration data for some elements of the inventory, with the remainder providing verification for the estimates of carbon stocks and stock changes arrived at through inventory methods.

Module B is based on the ~500 potential plots on the 16 x 16 km transnational grid (Hendry, 2001) and provides more detailed measurements of stocks at specific plots, also overlying the NIWT2 sample square grid. This network can also provide an independent upscaled estimate of measured stocks and stock changes of carbon at national level, as has already been carried out for Europe by De Vries *et al*. (2003). Module B will also provide more detailed mensuration measurements than those outlined in Smith (2004) and proposed for NIWT2, providing verification for yield models for some non-conventional species and management approaches that are not covered by Edwards and Christie (1981). More detailed soil and mensuration measurements will be carried out within the EU Level I plots and mensuration permanent sample plots in Module C providing verification of the models used to generate the modelled national carbon stocks from Module A. Finally, the very detailed measurements made within Module D, incorporating flux stations and the Level II Intensive Forest Health Monitoring Network, will provide further verification of the approaches used to generate modelled and upscaled national carbon stocks from Modules A and B. At the same time, Module D will provide information on changes to growth rate attributable to climate change and other environmental factors, together with a range of input parameters required to develop and run process-based models of forest growth from which independent estimates of stock changes can be derived.

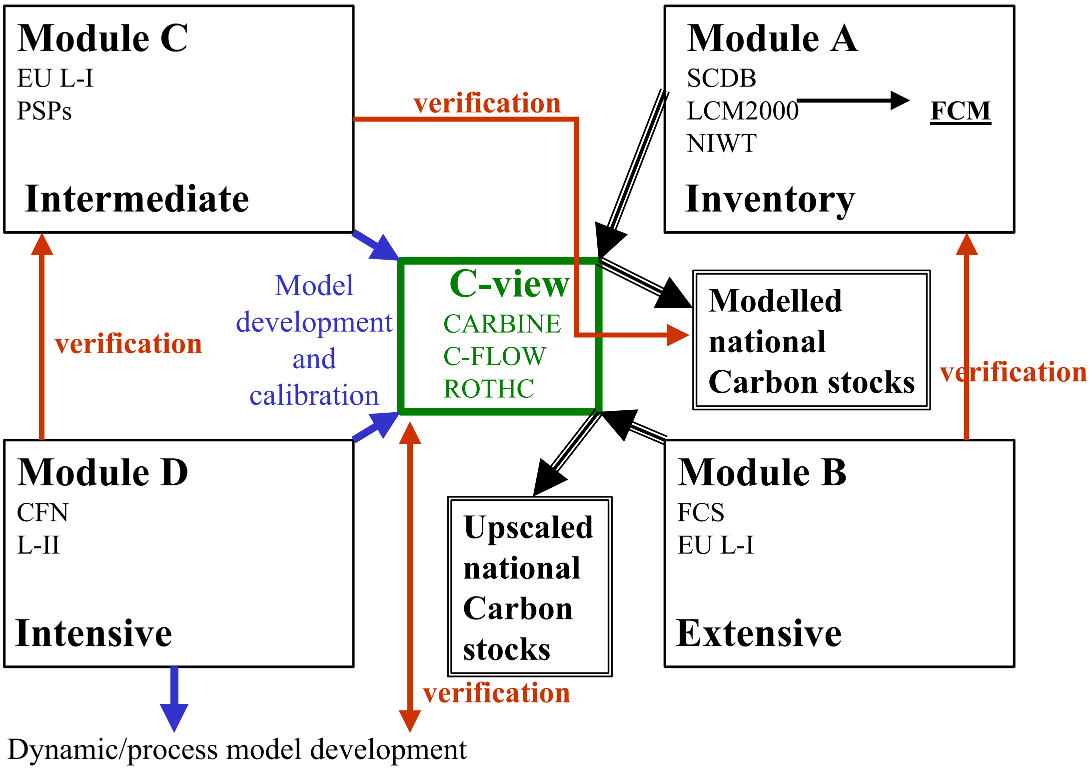

Figure 8-4. Schematic representation of the proposed carbon monitoring network.

8.9. Selection of pilot study areas

The location of the two pilot study areas cannot be finalised before the outcome of the consultation period over NIWT2 is known, as the cost of conducting the field assessments outside of the National Inventory would be prohibitive. However, it is intended that the two pilot study areas will contain at least one UNECE/ICP-Forests Level II plot and one flux station to demonstrate how measurements made within these more intensive networks can be incorporated within the verification process as described in a preceding section. In addition, it is hoped that the more northerly of the two sites will be within the footprint of the high tower in Perthshire, as described elsewhere in this report.

At present, the favoured locations are Hampshire/Surrey borders (including the Level II site and flux station at Alice Holt) and Tayside (including the Edinburgh University flux station at Aberfeldy and the Level II plots at Rannoch and Tummel). The nature of woodland is very difficult with large, contiguous areas of production conifer forestry dominating in Tayside, and a heterogenous landcover of small areas of mixed and broadleaf woodland dominating in Hampshire/Surrey. The exact location of the pilot study areas will be determined by maximising the number of intersecting points of the transnational 16 x16 km grid on which the UNECE/ICP-Forests Forest Condition Monitoring Network is based across most of Europe.

8.10. Outlook for 2004-5

The NIWT consultation process is due to be completed during July 2004, enabling the protocols operating within this project to be finalised. The sampling procedure for the wider Woodland Inventory will also be finalised, allowing a regional timetable to be developed, including

assessments in the proposed pilot study areas. It should thus be possible to provide a definitive boundary to the pilot areas, and also to identify the plots that align to the transnational 16 x 16 km grid (FCS and Level I). A detailed timetable will then be developed for fieldwork in late summer 2004 and for the remaining fieldwork during the summer of 2005. With the identity of the pilot areas known, estimates of carbon stocks in Forestry Commission woodland will be developed according to the protocols described here, including non-timber biomass fractions and soil carbon. A detailed manual for estimates of carbon stocks will also be prepared, based on the methodologies adopted in NIWT and described in general terms in this document.

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