Social & Environmental Benefits of Forestry
Phase 2 :

CARBON SEQUESTRATION BENEFITS OF WOODLAND

Report to

Forestry Commission

Edinburgh

from

Julii Brainard, Andrew Lovett and Ian Bateman

Centre for Social & Economic Research on the Global Environment
School of Environmental Sciences
University of East Anglia

June 2003

Social & Environmental Benefits of Forestry
Phase 2:

CARBON SEQUESTRATION BENEFITS OF WOODLAND

Julii Brainard, Andrew Lovett, and Ian Bateman

June 2003

1. Introduction

Evidence suggests that global warming is underway, and that at least part of this is attributable to the anthropogenic emission of greenhouse gases (GHGs). In terms of sheer volume, the most important single GHG is carbon dioxide (CO_2), which was estimated to comprise 84% of the total global warming potential of UK GHG releases in the year 2000 (DEFRA, 2002).

A social and environmental benefit of woodland is the extent to which it can contribute to the policy objective of reducing CO_2 in the atmosphere by locking up carbon through carbon sequestration. Carbon stored in existing woodland and carbon accumulating into existing and new forests create social benefits by keeping that carbon out of the atmosphere.

Carbon sequestration is a pure international public good. It has equal benefit to everyone. One tonne of carbon locked up in Scotland has the same value as one tonne locked up in Wales, as a contribution to reducing global warming. Hence the value of carbon sequestration is not subject to some of the problems that affect the estimation of other externalities from forestry such as recreation, landscape and amenity, and biodiversity. For instance, all of the latter need to be calculated with reference to the numbers of persons who receive direct or indirect benefit. Determining who benefits, whether the benefits are direct or indirect, or what proportion of benefit should be assigned to specific groups at which value, are not issues with carbon storage.

Two principal issues concern this study: the *net* carbon sequestration under forestry; and the value per tonne of carbon sequestration. Carbon storage associated with woodland land use occurs primarily in live wood, soils and harvested products. The carbon locked into live wood is directly linked to timber volume which itself is a function of tree species. Timber volume information is generally available for Forest Enterprise-managed areas, but not for private woodland holdings. The latter therefore had to be modelled using the relationships between environmental characteristics and observed timber productivity in the FE-managed estate. Lifetime analyses had been previously conducted by the authors and were applied in this study to consider the release of carbon from woody products. The carbon held in soils can be much greater than that in trees or products. Carbon losses are also possible, however, in the case of trees planted on peatlands. In all cases the rate of sequestration (or loss) is at least as if not more important than the cumulative totals.

In this study carbon sequestration is modelled for each unit of woodland (at a sub-compartment level) and then aggregated for regions of Britain. There is no agreed single social monetary value for carbon emissions into the atmosphere. Hence an appropriate range of social values for carbon are considered, from a review of recent literature. The carbon value is not static over time; carbon locked up today or in the near future is worth more than that sequestered in the distant future. This decline in value is quantified in our study by several different discount rates.

2. Methodology Overview

The analysis applies to most of Great Britain (England, Wales, Scotland, and immediate offshore islands) but excludes the Channel Islands, Isle of Man and Scilly Isles. We characterise woodland by management, with sites managed by Forest Enterprise described as Forestry Commission (FC) "estate", and all other woodland referred to as "private" holdings (although in many cases these areas may be under at least partial public ownership, through county councils for instance). Three species groups in the FC estate were subset for individual analysis: Sitka spruce (*Picea sitchensis*), oak (*Quercus* species) and beech (*Fagus sylvatica*). Sitka spruce is the softwood species with greatest areal coverage in Great Britain (about 49% of GB total area planted in conifers; FC 2001a). By area, oaks are the single most common broadleaf species in the FC estate, comprising approximately 10% of hardwood plantings, with beech making up another 3.5% of broadleaf areas.

Carbon storage in live wood is directly linked to timber volume, which in turn is described in terms of expected productivity, or *yield class* (YC). In the Forestry Commission estate, yield class was generally provided with individual subcompartment (SC) records. However, such data are not available for private woodland in sources such as the Woodland Inventory (WI). Instead we modelled the relationship between yield class and environmental variables in the FC estate, and applied these functions predict YC on private holdings. Yield class (and carbon sequestration) models for Sitka spruce and beech were used to represent the general categories of coniferous and broadleaf trees.

Yield class is just one of many variables relevant to carbon sequestration. It was necessary to determine the predominant soil type for each stand of trees, the stand area and proportion of afforested area (many sites designated as woodland are not 100% woodland). The rotation and year of current planting, as well as original afforestation date of the site also needed to be determined or estimated. Where woodland was designated as "mixed" species, assumptions were made about the likely predominant species (i.e. broadleaf or conifer).

Geographical Information Systems (GIS) techniques were used to link the forestry information with other environmental data. For numerical climate and topography variables, each woodland plot was assigned the mean value of cells coinciding with that SC. SC's were given the categorical values for soil characteristics coinciding with the majority of the SC. Some SC's were very small or unusual shapes (e.g., long and thin), and had to be assigned values manually rather than in an automated manner.

Once the data sources were integrated, regression techniques were applied to predict yield classes for all forest and woodland areas. A combination of spreadsheet and

Perl programming techniques were used to calculate the corresponding amounts of sequestered carbon and to derive values under different scenarios. Finally, the values were aggregated for Government Office Regions and presented in table form.

3. Data

3.1 Variables

Table 1 summarises the data and sources used to determine first yield class, and then carbon sequestration. The top eight variables in Table 1 come from the Forestry Commission's own subcompartment database (FC SCDB), described below. The FC SCDB is a digital catalogue of all land managed by the FC's management arm, Forestry Enterprise. For subsequent analysis, we subset from the SCDB just those subcompartments (SCs) that are managed for timber extraction.

Table 1. Variables used to calculate Yield Class and Carbon Sequestration potential

Name	Description
From the FC subcompartment database, or directly derived from same:	
YC	Yield Class
AREAA	Total area in ha
AREAP	Proportion of area planted in trees
PLYR	Year when planted
ROTN	Rotation (1=1st; 2=2nd; 9=more than 2nd; S=semi-natural management regime)
SDATE	Year when surveyed
AWS	Time (in years) between planting and survey date
SPACE	Spacing in metres between trees on SC
Calculated within the GIS:	
DAMS	Windiness score *(supplied by Forest Research, 250m resolution)*
NORTH and EAST	Grid reference (northing and easting) of area centroid (centroid location determined by GIS; and constrained to be within the boundaries of the SC).
From data supplied by the National Soil Resources Institute (NSRI) and Macaulay Land Use Research Institute (MLURI); 1 km resolution soil attributes codes as categorical variables. The attribute value coinciding with the majority of the SC was used as that for the entire SC. 1x1km resolution	
FERT	Predominant fertility category: 1=pH<5; 2=pH=5-7;3=pH>7;0=lakes;9=rocks and scree.
WET	Predominant wetness category (1=dry;2=moist;3=wet;4=saturated (England only); 9=rocks;0=lakes)
DEPTH	Predominant soil depth category (1=rock at 0-40cm; 2=rock at 40-80cm; 3=rock at >80cm; 9=rocks+screes; 0=lakes)
Using 10km resolution data supplied by the Climate Impacts LINK Project, Climatic Research Unit, University of East Anglia at UEA and calculated as averages across the subcompartment within the GIS:	
MINT	Average (Celsius) of minimum temperatures in four winter months: November- February
MEANT	Average of mean temperatures for six months April-October
MAXT	Average of maximum temperatures in June-September
RAIN	Annual rainfall in mm
From NSRI and MLURI (as above) 1x1km resolution	
SOIL CARBON	Coded as mineral, thin peat (<45cm deep) or thick (>45cm deep) peat soil
Directly or derived from Ordnance Survey 50 m elevation model (Panorama data).	
ELEV	Elevation
ASPECT	Mean aspect, in radians from due north
SLOPE	Mean slope

3.2 Woodland cover

Digital woodland cover in GB came from three data sources: the FC subcompartment database (FC SCDB), the Woodland Inventory (WI), and ancient woodland cover in England.

The FC SCDB includes digital boundaries of all FC subcompartments, usually with land use, species, rotation, planting year and yield class attributes. The data were provided in 2001 and are nominally accurate to that year. The WI was derived from aerial photographs. In Scotland the WI is based on photos mostly dated 1988-1989, . photos for England and Wales were all taken in the period 1991-2000. Supplemental information digitised for later plantings by the FC and under the Woodland Grant Scheme. Only areas two ha or larger were mapped in the WI, which is believed to exclude no more than 5% of GB woodland. The data categorise woodland using feature codes and descriptors that often, but not always, give some indication of likely species and age. The complete WI dataset encompassed the FC estate and therefore the FC estate had to be excised from the WI data to give separate estimates of carbon sequestration in private woodland. We refer to individual, contiguous WI areas with the same descriptor code as WI “subcompartments” (i.e., WI SCs), although it is unlikely that most such areas were actually managed as single units.

Point grid references for 22,572 ancient woodlands (AW) in England were downloaded from the National Digital Archive of Datasets (NDAD, URL=*ndad.ulcc.ac.uk*). These data were originally compiled by English Nature in the period 1986-2002, and designate areas in England that have been in continuous woodland cover since the year 1600 or earlier until the 1920s. Numerous attributes were provided with the AW cover, including total afforested area (in hectares) and current site condition (“Good”, “Unknown” or “Poor”). Boundary information for AW sites was not available at the NDAD[1]. Instead, we approximated the boundaries by assuming that each AW had a perfectly circular shape with the given point grid reference at its centre. The given total area of a specific AW was used to derive the circle radius. Centroids for WI areas were overlain with AW circles to identify WI sites that were possibly ancient woodlands.

Yield class, species, planting year and rotation data were vital inputs to the carbon sequestration models. Where these variables were missing, we generally assigned them using the observed proportions for the known FC subcompartments (SC’s), and as reported in FC (2001a). For instance, many stands in the WI are designated mixed conifer or broadleaf. Our models are not designed to handle mixed species woodland. According to FC (2001a) 71% of afforested, non-FC land in Scotland, and 29% of such areas in England or Wales are coniferous. We therefore randomly assigned WI SC’s of unknown species types to be nominally conifers or broadleaf, based on these reported proportions for Scotland and England/Wales. Similarly, in the FC SCDB 28% of conifer plantations were in their 2nd rotation, and the mean planting year for this group was 1974. This planting year value was assigned for any WI SC previously designated as coniferous and in its 2nd rotation. Tree spacing and the

---

[1] The English Nature website (www.english-nature.org.uk) enables downloads of digital boundaries of ancient woodlands for some parts of England. These data were not available in a format we could readily make use of, and nor do we know of comparable data for Scottish or Welsh ancient woodland sites.

proportion of a subcompartment are also important in some parts of the analysis, and such details are not always provided. 74% of all oak, 89% of all beech, 50% of FC broadleaf and 68% of FC conifer subcompartments with no yield class had spacing of 1.7m. Spacing values on Sitka SCs were almost evenly split between 2m (48.1%) and 1.7m (47.8%). Where missing, a universal spacing value of 1.7m was generally assigned, with 2m being used for Sitka spruce. The mean proportion of afforested area on individual plots turned out to be an important predictive variable for yield class. Where missing, the mean values observed in the FC SCDB were used (64% for oak and beech, 73% for conifers).

Table 2 gives some summary statistics for missing variable assignments in the FC estate. The data in Table 2 apply to oak, beech, Sitka spruce and FC stands with unknown YC. Otherwise, rotation and planting year for these woodland types are those noted in the FC SCDB. However, it considerably facilitated analysis to use generalised rotation and planting year assignments for the remainder of the FC estate (with known YC). The actual values to assign were determined following the observed proportions in the remainder of the FC estate. For instance, 63% of non-Sitka conifer stands in the FC estate are in their first rotation, with a mean planting year of 1953. Therefore, when rotation was missing, we tried to assign 66% of non-Sitka spruce FC conifers to have rotation=1, planting year = 1953. 26% of non-Sitka conifers are in their second rotation, with a mean planting year of 1974. Approximately 26% of FC subcompartments without rotation values were assumed to be in second rotation, with a planting year=1974. It was very difficult to replicate these proportions exactly when assigning rotation/plant year values, but Table 3 shows that the resulting proportions are fairly close.

No rotation records were available for the WI. We assume that the FC proportions of first, second and greater rotation are roughly applicable. Rotation values were assigned randomly to subcompartments, taking on (approximately) the observed proportions in the FC SCDB. In the FC SCDB the ROTN=9 category had the oldest average planting dates, ROTN=1 is a next eldest, and ROTN=2 had the most recent planting dates. We assume that this order also applies for private woodlands. Actual planting dates were generalised from data in the National Inventory of Wood and Trees (NIWT), which supplements the WI. The NIWT contains field survey information on an approximate one per cent sample of WI areas. FC (2001b, 2001c, 2002) gives statistics for age profiles in the NIWT, broken down by species type (coniferous or deciduous) in England, Scotland and Wales. We used these data to assign very generalised typical planting year values to each rotation and consequently to each subcompartment, as shown in Table 3.

Rotation and planting year assignments were further revised when a WI centroid seemed to within an ancient woodland area, as found by our overlay of approximate AW boundaries (circles) and the WI centroids. The WI codes were considered before a woodland could be treated as “ancient”. For instance, WI code 85 is young trees that cannot be allocated between conifers or broadleaves. In this case, although we may assume that the site was formerly ancient woodland, it obviously no longer contains ancient trees. In such cases we assign a recent planting year (1980 if broadleaves, 1990 if conifers), but a high rotation value (ROTN=9). These rules may underestimate the carbon stored from previous rotations on such sites, but the strategy seems appropriate given the uncertainty about the exact boundaries of the ancient woodland data. Where mature woodland currently stands on an AW site, a planting year of 1874 is assigned. This year asssignment is somewhat arbitrary, but it was made with reference to profiles in FC (2001a) of age classes of GB woodland. Empirically, we found that to assign 1874 as the planting year for these 'ancient' sites led to good overall agreement with the age profiles suggested in FC (2001a). The condition of the site was also important. 75% of sites were designated "Unknown", 13.5% "Poor" and 11.5% "Good" (or "Reasonable"). Where condition is known, sites are therefore more likely to be in poor than good condition. We take a conservative approach and assume that only those AWs in good condition will continue to be managed conservatively. They are assigned very long rotations, of 350 years, and currently are assumed to be in their third rotation. Sites in unknown or poor condition are given a shorter felling gap, of 130 years. Both unknown and poor condition sites are treated as though they were in the first rotation in 1874, and are restocked with timber crops grown for their cash value (with corresponding felling ages). These rules ignore carbon that may have accrued before 1874 on poor and unknown site, but they also assume that mature forest currently on a site means that no felling has occurred between 1874 and the year 2004. It would be remiss to suggest that these assumptions around possible AWs are perfect, but they do give some recognition to likely ancient woodland sites, whilst being unlikely to produce excessive estimates of carbon stores. Table 3 gives further details about how ROTN and PLYR values were assigned for possible ancient woodland sites.

Table 2. Number of FC subcompartments (SCs) with missing data for given variables.

	Subcompartments (%) missing data			
Species (No. of SCs)	Current planting year	Rotation	Spacing	Yield Class
Beech (5689)	140 (2.46%)	0	201 (3.53%)	1604 (28.19%)
Oak (7128)	532 (7.46%)	0	473 (6.64%)	2960 (41.53%)
Sitka (74,067)	43 (0.06%)	0	1241 (1.68%)	5375 (7.26%)
Other FC broadleaf with unknown YC	7438 (26.37%)	0	2399 (8.50%)	28,211 (100%)
Other FC conifer with unknown YC	490 (10.49%)	264 (5.65%)	270 (5.78%)	4669 (100%)

Table 3. Area percentages with assigned planting year/rotation attributes in FC and private woodland.

Species	Current planting year And rotation (% of total area)
Known YC, FC broadleaf (not oak or beech)	PLYR=1958, ROTN = 1, (26.48%)
	PLYR=1989, ROTN = 2, (25.86%)
	PLYR=1949, ROTN = 9, (47.65%)
Known YC, FC conifer (not Sitka spruce)	PLYR=1953, ROTN = 1, (61.94%)
	PLYR=1974, ROTN = 2, (27.44%)
	PLYR=1929, ROTN = 9, (10.62%)
Private broadleaf	*England, Scotland and Wales*
	PLYR=1935, ROTN = 1, (26-33%)
	PLYR=1974, ROTN = 2, (21-25%)
	PLYR=1905, ROTN = 9, (46-47%)
Private conifer	*England*
	PLYR=1953, ROTN = 1, (54%)
	PLYR=1974, ROTN = 2, (28%)
	PLYR=1929, ROTN = 9, (7%)
	Wales
	PLYR=1965, ROTN = 1, (57%)
	PLYR=1989, ROTN = 2, (33%)
	PLYR=1906, ROTN = 9, (7%)
	Scotland
	PLYR=1975, ROTN = 1, (42%)
	PLYR=1989, ROTN = 2, (20%)
	PLYR=1906, ROTN = 9, (6%)
Modifications to general rules.	
FC=7	New planting in period 1988-1996, ROTN=1, PLYR=1993
FC=11	New planting in period 1995-2001, ROTN=1, PLYR=1998
FC=83	Newly converted land from non-woodland to Woodland, ROTN=1, PLYR=1998
FC=84	Felled woodland ROTN=2 or 9, PLYR=1998
FC=85, 68	Young trees, if broadleaf, PLYR=1980 if conifer, PLYR= 1990
FC=73	Semi-natural conifers in Scotland, sometimes ancient woodland, ROTN=9, PLYR=1906
FC=7,11 or 85 and Ancient woodland	ROTN=9, PLYR same as above
FC=82 and Ancient	Shrub that may be woodland, ROTN=9, PLYR=1990
FC=88, 89	Coppice (only England), ROTN=9, PLYR=1992
FC=70, 76, 79 and Ancient woodland	PLYR=1874. Good condition, Felling age = 350, ROTN=9 Unknown or poor condition, Felling age = 130, ROTN=1

Note: FC = Woodland Inventory Feature Code.

3.3 Soils

A considerable proportion of carbon sequestration associated with woodland is in soils. Most soils are in carbon balance: the carbon deposited there in vegetative matter is approximately equal to the carbon being released by the decaying organic materials back into the atmosphere. The equilibrium levels are partially dependent on vegetation and land use, with afforested areas tending to have higher equilibrum levels of soil carbon than pasture or farmland. The decomposition of carbon from decaying organic matter is severely delayed under anaerobic conditions, however, such as when soils are poorly drained or frequently waterlogged, forming peat (Askew *et al.* 1985). As a result, many British peat bogs have an ongoing net annual increase of soil carbon. Drainage of peat (necessary as a precursor to afforestation) removes the anaerobic conditions, leading to new soil carbon equilibrium levels. The result is a considerable and extended period of carbon releases on afforested peat wetlands into the atmosphere as CO_2. Research into the exact rate of carbon losses on afforested peat in Great Britain is ongoing. There is no predetermined upper limit for the carbon levels in peat soils, and the widespread afforestation of such soils in the latter half of the last century significantly complicates the calculation of net carbon storage benefits from forestry.

Data from the National Soil Resources Institute and Macaulay Land Use Research Institute were provided to indicate the presence of mineral (i.e., non-peat), thin (<45 cm depth) peat and thick (>45cm depth) peat soils in GB in 1x1 km squares. Each woodland area (FC or WI SC) was assigned the soil status (non-peat, thin peat or thick peat) of the area coinciding with the majority of that SC.

Adger *et al.* (1992) reported equilibrium soil carbon levels for a variety of soils and land uses. This work was supplemented by conversations with Professor David Jenkinson (Rothamsted), Dr. Robert Sheil (University of Newcastle upon Tyne) and Professor Steven McGrath (Rothamsted) to derive estimates of the full range of soil carbon changes that could be expected to result from afforestation of various soil types. The initial expected soil carbon gains and losses are reported in Bateman and Lovett (2000), reprinted in Table 4. Positive values predict gains (i.e., sequestration); negative values indicate expected losses (i.e., peat soils are believed to typically become net carbon sources, post-afforestation).

For our purposes, upland was defined as those areas at 150m elevation or above. The selection of 150m was somewhat arbitrary. Unfortunately, the definitions of ‘upland’ and ‘lowland’ tended to vary between the studies that Bateman and Lovett (2000) reviewed to derive the figures in Table 4. Sometimes upland refers more to a habitat type and not elevation. This perspective was taken to define upland areas in the Countryside Survey 2000 (Haines-Young *et al.*, 2000). We were disinclined to use the CS2000 data, however, as they are relatively generalised compared to the detail of the rest of our information. However, we are reassured that our map of upland areas seems to closely agree with the CS2000 maps of upland and marginal upland areas.

Table 4 suggests that the actual post-afforestation changes in carbon can be highly variable. For any specific site, field measurements would need to be made to determine precise carbon storage changes. Otherwise, some very generalised values can be extracted from Table 4. As long as these assumptions are applied over relatively large and diverse geographic areas, they should be realistic averages. In non-peat soils, it appears that gains of 50 tC/ha for uplands, and 100 tC/ha for lowlands, could typically be expected.

Table 4. Post-afforestation changes in equilibrium soil carbon storage levels for various soils previously under grass (tC/ha): upland and lowland sites.

Soil type	Upland sites			Lowland sites		
	Under grass	Under trees	Change	Under grass	Under trees	Change
Peat	1200	450	-750	n/a	n/a	n/a
Humic gley	180-400	250-450	50-70	180-350	180-450	0-100
Podzol	200-400	250-450	50	100-200	100-450	0-250
Brown earths	n/a	n/a	n/a	100-120	100-250	0-130
Humic stagno podzol	180-400	250-450	50-70	120-350	120-450	0-100
Stagnogley	170-400	170-450	0-50	100-120	100-450	0-330

Source: Bateman and Lovett (2000).

Both the total gains (or losses) and rate of loss are critical to our predictions of social value. New carbon sequestration in afforested non-peat soils is assumed to occur over a 265 year period. Robert Sheil (pers. comm., 1994) suggests that about 95% of the net change in soil carbon will occur within 200 years of planting. Bateman and Lovett (2000) fit a regression curve to soil carbon storage curves reported in Sampson (1992), Dewar and Cannell (1992) and Matthews (1993), to produce a model predicting percentage of per annum soil carbon gain over time. The cumulative gain was constrained to equal 95% at two hundred years post afforestation. The model predicted 100% of total carbon gain at around 265 years post afforestation,

Uncertainty about the magnitude and rate of carbon loss on afforested peatlands lends uncertainty to our analysis. Early studies suggested that losses might range from 0.5 to 3 tC/ha yr^{-1} (Cannell and Milne 1995). Recent research revises these estimates downwards. From original field measurements and computer modelling, Hargreaves *et al*. (2001, 2003) of the Centre for Ecology and Hydrology (CEH) constructed a descriptive model of carbon exchanges on afforested peat soils in Scotland. We are obliged to Ronnie Milne at CEH for supplying us with the most recent CEH estimates of annual carbon flux on afforested peat areas (including ground vegetation and litter), which we have generalised for our own modelling and are listed in Table 5. The data only extend to year 26 after afforestation. Milne's models indicate (pers. comm. 2003), based on the measurements taken at several study sites with trees of different ages (a "chronosequence"), that afforested peat might emit carbon long term at a rate of about 0.3 t/ha per year. We treat this value (0.3tC/ha) as the upper limit of expected annual losses on afforested peat after 26 years. This loss continues in perpetuity, or until the total expected maximum is reached, e.g., 750 tC/ha for deep peat soils. Lacking further information about carbon releases from thin peat soils, we assume that these are approximately 15% of the suggested maximum from thick peat soils, or 112 tC/ha. This potential loss for thin peats may be too low, given that peat soils in Wales are estimated to contain a mean value of 250 tC/ha in just the top 15 cm, compared to only 20 tC/ha to the same soil depth for Welsh agricultural soils

(CEH 2002). Because of the considerable uncertainty regarding the magnitude of the possible carbon losses on afforested peat, our final tables include separate calculations for planting on thin or thick peats. Also, a sensitivity analysis was undertaken (see Section 6.1.1) to investigate possible effects of our assumptions about the rate of afforested peat carbon losses on the final valuations.

Undisturbed peat bogs in upper latitudes generally act as a sink for carbon; organic matter deposited in these locations adds to the carbon storage[2]. The rate of accumulation in northern peatlands has been estimated at 0.4-0.7 tC ha^{-1} yr^{-1} in Cannell and Milne (1995), and 0.2-0.5 tC/ha/yr (Cannell 1999). Hargreaves *et al.* (2001) observed actual carbon accumulation rates on undisturbed peat of 0.22 and 0.25 tC/ha yr^{-1} at two Scottish sites. Crill *et al*. (2000) report a somewhat lower value for Finnish peatland, of just 0.205 tC ha^{-1} yr^{-1}. Where planting is on deep peat soils, the final models adopted the relatively low adjustment (subtraction in net carbon stocks) of 0.25 tC/ha/yr for this lost carbon sink through to the year 2021. After 2021, it becomes more likely that temperature rises will cause many peat soils to cease absorbing carbon, and they may even change to net C sources (Bousquet *et al*. 2000), particularly in Scotland (Chapman and Thurlow 1998). Thin peat soils are assumed to offer a lost potential sink of 0.0375 tC/ha/yr (15% of 0.25) tC/ha until 2022. The size of these sinks turns out to have much effect in our models (see sensitivity analysis in Section 6.1.1).

Table 5. Generalised carbon losses from peat, leaf litter and ground vegetation on afforested deep peat soils.

Years after Planting	Generalised Carbon loss	Years after Planting	Generalised Carbon loss
0	0.08	14	-0.3
1	2.2	15	-0.2
2	3.8	16	-0.1
3	2.5	17	-0.04
4	1	18	0.03
5	-0.27	19	0.08
6	-1.2	20	0.12
7	-1.6	21	0.15
8	-1.6	22	0.18
9	-1.3	23	0.2
10	-1.1	24	0.22
11	-0.8	25	0.24
12	-0.6	26	0.25
13	-0.5		

Source: Milne (pers. comm., 2003). Negative values denote periods of carbon gains in the peat (i.e., gains rather than losses). A constant loss of 0.3 tC/ha per annum is assumed from year 27 onwards.

---

[2] The situation is complicated because undisturbed peatlands emit a potent greenhouse gas: methane (see discussion in section 5.4.5), but afforested peat absorbs methane. The potential tradeoff in global warming potential is a chief reason why Cannell and Milne (1995) did not include the lost C sink in their calculations of GB carbon pools.

4. Yield Class Models

4.1 Model form:

Carbon sequestration in live trees is closely related to timber volume, or what foresters term *yield class* (YC). YC is rounded up to the nearest even integer, and denotes (in cubic metres) the maximum mean annual increment in timber production, per hectare, over the stand's entire rotation. For instance, YC14 denotes a stand that produces, in its most productive seasons, an average of 12-14 m^3/ha/yr over the entire rotation to date. Regression models were used to relate YC, where known, with other environmental characteristics. These models were then used to predict YC where the variable was otherwise missing. Initially we used Ordinary Least Squares (OLS) regression techniques, but concluded that these were unsatisfactory in several respects. Several models had large negative constant terms, and the OLS form allowed model predictions to take an improbably high number of extreme values; this problem with OLS was also noted in yield class modelling by Matthews and Methley (1996). To circumvent these issues, we adopted ordinal regression methods (McCullagh, 1980; Menard, 2001) for the main part of the work.

In ordinal regression (OR), the model predicts, for each category (in our case YC) a value which is a transformation of the cumulative probability of the observation belonging to that YC. The transformation function is referred to as the link function, and can take many forms. We achieved the highest explanatory power (as indicated by pseudo-R^2 statistics) using a logit link function for all cases except beech. The logit function takes the form:

$$\log(y/1-y)$$

where y is the cumulative (sequential) probability of a record belonging to a specific category. Log() refers to natural logarithm.

The complementary log-log function used for beech is

$$\log(-\log(1-y))$$

In addition to variable coefficients, the models calculate a threshold value for all but the highest ordinal category (no separate threshold is needed for the highest category, because its probability is one minus the sum of all previous probabilities). Just as in an ordinary least squares regression model, each coefficient is multiplied by the independent variable values for a specific observation, and these factors are summed together. Positive coefficients increase yield class, negative coefficients decrease YC. The result is subtracted from the threshold value, to achieve a linear predictor, which must be transformed by the inverse of the link function, to obtain a cumulative probability. The differences between cumulative probabilities generate individual probabilities of being in each YC. The category with the greatest predicted probability is the model prediction.

Because of the link function, it may be hard to interpret the magnitude of influence of variables in the following models. However, by empirical testing, we found that in our models, any change of 0.1 or higher in the initial predicted value may be enough to alter yield class predictions.

The fitting of the regression models followed an iterative procedure involving considerable experimentation regarding the most appropriate transformations for the independent variables. It is worth noting that OR works better in situations where there are few rather than many possible outcomes; for that reason, it tended to perform better for the broadleaf species, with only 4-5 possible YC values (2-10), as opposed to the range of Sitka spruce YCs (2-22). However, the immense advantage and appeal of OR is that only credible values can be predicted (e.g., unlike Ordinary Least Squares regression it is impossible to have predicted YCs outside those observed in the data used to derive the model).

Strength of model fit can be assessed in various ways. Standard errors and significance values are produced and can be interpreted as usual for each variable. A conventional regression analysis would also output an R-squared (R^2) value. An R^2 value gives the proportion of the total variation of the dependent variable (YC in this case) around its mean, which can be explained by, or attributed to, the regression. It is taken as a measure of the “goodness of fit” of the regression. By definition, R^2 values are constrained to the range 0-1 (or 0-100%), with higher values indicating better model fit. The nature of ordinal regression techniques do not enable the calculation of R^2 values by usual methods, but the software used by the analysts (SPSS) did output several possible psuedo-R^2 values: Cox and Snell (1989), Nagelkerke (1991) and McFadden. The McFadden statistic is often considered to be most reliable if also most stringent. Both the McFadden and Cox and Snell measures are constrained (with categorical outcomes) to a theoretical maximum value less than 1.0. Nagelkerke (1991) modified the Cox and Snell R^2 to allow it take on values in the full range of zero to one, making the Nagelkerke pseudo-R^2 more comparable to a conventional R^2 statistic.

The other principal means of assessing model fit is to cross-tabulate predicted with observed values. These cross-tabulations are given for each model, along with some summary notes.

4.2 YC Models: Beech

The initial set of beech records in the FC SCDB were reduced from 5,997 to 1,985 by removing records with YC = 0, YC > 10, PLYR < 1800, mixed species stands and those SC’s not plantation high forest. We obtained better fit for beech using a complementary log-log link function, rather than the logit function. In Model 1 several variables worked best at a power of 2 or 3 (i.e., DAMS and ELEV). In the case of $ELEV^3$, this variable has negligible effect on YC below elevations around 300-350 m. Similarly, low DAMS scores do not significantly impact beech YC, but high DAMS scores are increasingly important.

51.9% of predictions are in the correct YC. 43.17% are only displaced by one YC. This high level of accuracy is somewhat to be expected, given that there are only a total of five possible YCs. The results are shown in Tables 6 and 7.

Table 6. Beech YLDC and Predicted Response Category Crosstabulation.

		Predicted Response Category				**Total**
		2	**4**	**6**	**8**	
YLDC	**2**	**6**	29	21	5	61
	4		**10**	199	56	265
	6		12	**509**	306	827
	8			232	**505**	737
	10			16	79	95
Total		6	51	977	951	1985

Model 1. Beech.

		Estimate	**Std. Error**	**Sig.**
Threshold	[YLDC = 2]	21.567	7.608	.005
	[YLDC = 4]	23.439	7.608	.002
	[YLDC = 6]	25.211	7.612	.001
	[YLDC = 8]	26.691	7.613	.000
Variables	AREAA	9.282E-07	.000	.137
	AREAP	6.437E-03	.001	.000
	PLYR	1.015E-02	.001	.000
	MAXT	1.129	.788	.152
	MAXT^2	-2.789E-02	.021	.192
	NORTH	-4.451E-07	.000	.096
	EAST	-7.971E-06	.000	.000
	SPACING	-1.769	.339	.000
	ELEV^3	-2.029E-08	.000	.000
	RAINEAST	1.072E-08	.000	.000
	EASTFACE	8.593E-02	.036	.017
	ROT9	.518	.064	.000
	DAMS^2	-5.212E-03	.001	.000
	TOOWET	-.238	.074	.001
	SQRSLOPE	-.148	.036	.000
	RAIN	-2.638E-03	.001	.000

Link function: Complementary Log-log.

Notes:
EASTFACE = eastern facing aspect
ROT9 = rotation category = 9
TOOWET = WET category = 3 or 4
SQRSLOPE = square root of SLOPE

Table 7. Pseudo R-Square for Model (1).

Cox and Snell	.491
Nagelkerke	.534
McFadden	.269

4.3 YC Models: Oak

In the FC subcompartment (SC) database there were 7,128 records. Of these, only 2,171 were pure stands with non-zero YC. Upon removal of SC's planted before 1900, a handful of SC's with YC > 8, and those surveyed when relatively young or old (i.e., before 17 or after 100 years of age), 978 cases remained to derive Model 2 to predict YC in oak. Note that in the cross tabulation (Table 8) no predictions have been made for YC = 8.

Table 8 shows that 65.2% of predictions were for the correct YC, with another 33.8% of predictions only one YC out. However, it must be recalled that this high level of apparent model performance is partly a reflection of the low number of possible YCs.

Table 8. Oak YLDC and Predicted Response Category Crosstabulation.

		Predicted Response Category			Total SC's
		2	**4**	**6**	
YLDC	**2**	3	29	3	35
	4	6	337	129	472
	6		128	298	426
	8		6	39	45
Total		9	500	469	978

Table 9. Pseudo R-Square for Model (2).

Cox and Snell	.292
Nagelkerke	.341
McFadden	.177

Model 2. Oak

		Estimate	Std. Error	Sig.
Threshold	[YLDC = 2]	89.507	8.628	.000
	[YLDC = 4]	93.981	8.702	.000
	[YLDC = 6]	97.505	8.738	.000
Variables	DAMS	-.318	.050	.000
	PLYR	4.854E-02	.005	.000
	EAST	2.851E-05	.000	.000
	$EAST^2$	-3.106E-11	.000	.000
	MINT	1.513	.310	.000
	$MINT^2$	-.258	.081	.001
	SPACING	-7.499	1.394	.000
	LOGAP1	.956	.179	.000
	DEP1	-.797	.239	.001
	WET2	.376	.262	.151
	NEUT	.879	.223	.000
	NN	-5.067E-07	.000	.198
	RAINEAST	9.377E-09	.000	.000
	ELEV	8.175E-03	.005	.077
	$ELEV^2$	-1.183E-05	.000	.505
	ROT1	1.520	.423	.000
	ROT9	1.077	.387	.005

Notes:
RAINEAST = is rainfall * easting. It would appear that YC slightly increases in eastern locations if rainfall is also relatively high
NN = northing, * northern aspect (i.e., cos(ASPECT * pi/180). NN is positive where a site has predominantly northern aspect, and NN decreases yield as one moves north.
LOGAP1 = natural logarithm of the AREAP variable + .01
NEUT = if soil fertility is neutral (pH).
DEP1 = where soil depth category is 1
ROT1 = 1st rotation
ROT9 = Rotation value = 9 (i.e., higher than 2nd)

4.4 YC Models: Sitka

There were 74,067 Sitka records in the FC database with valid SC identifiers. Of these, 5,375 had missing data for YC. Another 1,718 were not Plantation High Forest. A further 14,077 were not pure stands (i.e., MIXT not = 'P'). 1,359 were eliminated for incomplete planting or survey date information. Eight had a planting proportion (AREAP) = 0, eleven had missing data for SPACE, and it was difficult to produce reliable estimates of the WET, FERT or DEPTH category descriptions for a further 1,442 SC's. Thus, we were left with 49,879 possible records to use in subsequent regression analysis.

We had most success with Sitka models by splitting them into northern and southern populations. 'Northern' refers to subcompartments with a northing grid reference above 419999. In practice, this division means that the northern population is mostly in Scotland, the southern group is almost entirely in Wales.

4.4.1 Models: Southern Sitka

5,721 (about 11.5% of possible total) observations were in the southern region, and were used to fit Model (3). No YCs above 24 were present in these data. 23.9% of observations have YC correctly predicted, with another 36.1% only one YC out. No predictions for YC 4, 8, 22 or 24 were made, although these values did indeed occur in the observations. 18.2% of predictions are more than two YC incorrect.

Model 3. Southern Sitka

		Estimate	**Std. Error**	**Sig.**
Threshold	[YLDC = 2]	76.325	10.391	.000
	[YLDC = 4]	76.527	10.391	.000
	[YLDC = 6]	77.420	10.392	.000
	[YLDC = 8]	78.112	10.392	.000
	[YLDC = 10]	78.945	10.393	.000
	[YLDC = 12]	80.000	10.394	.000
	[YLDC = 14]	80.977	10.396	.000
	[YLDC = 16]	82.011	10.397	.000
	[YLDC = 18]	82.940	10.398	.000
	[YLDC = 20]	84.068	10.398	.000
	[YLDC = 22]	84.915	10.399	.000
Location	DAMS	-.127	.013	.000
	MINT	-.149	.014	.000
	MINT^2	1.803E-03	.000	.000
	MAXT	10.651	1.218	.000
	MAXT^2	-.319	.035	.000
	ELEV^2	-9.408E-06	.000	.000
	SQRAP	.133	.013	.000
	LAA	.182	.021	.000
	ROT1	-.537	.057	.000
	WET4	-.576	.060	.000
	RAIN	-6.828E-03	.001	.000
	RAIN^2	2.760E-06	.000	.000
	NORTH	-8.354E-06	.000	.000

Notes:
LAA = natural log of AREAA
ROT1 = subcompartment in 1st rotation
WET4 = Soil wetness category = 4
DEP1 = soil depth category = 1
NORFACE = cos(ASPECT * pi/180) = north facing aspect

Table 10. Pseudo R-Square for Model (3).

Cox and Snell	.312
Nagelkerke	.316
McFadden	.085

Table 11. Southern Sitka and Predicted Response Category Crosstabulation.

	YLDC								
		2	**6**	**10**	**12**	**14**	**16**	**18**	**20**
YLDC	**2**	**26**	1	43	63	23	15	1	
	4	5		1	16	5	7		
	6	9	**2**	39	158	18	9		
	8	13	2	46	163	50	34		
	10	9	5	**40**	299	121	74	3	
	12	6	1	31	**443**	267	233	11	1
	14	5		15	360	**309**	344	16	19
	16	2		6	224	230	**462**	59	32
	18	1		2	104	122	329	**59**	34
	20			1	36	68	239	57	**29**
	22			1	17	25	78	18	6
	24	1		1	4	19	65	23	6
Total		77	11	226	1887	1257	1889	247	127

4.4.2 YC Models: Northern Sitka

Although it was possible to undertake regression analysis on the full set of Northern Sitka observations (35,554 Records), we found this to be very demanding computationally. Having used the full dataset to initially establish which variables were likely to be the best predictors of YC, further refinements were made using 12,443 observations chosen at random (35% of the northern total), to produce Model 4.

Model 4 looks very similar to Model 3. The net effect of the quadratic expression of the easting variable is as follows: YC increases as one moves east, but the increase is greatest, proportionately, in the most western locations. The greatest improvements happen from easting 120,000 (outer Hebrides) to easting 180,000 (Ullapool to Kintyre). The upward trend continues to accelerate until around easting 360,000 (coinciding with, from north to south, Banff/Macduff - Banchory - Arbroath - Crail - East Linton-Jedburgh).

Elevation operates similarly to EASTING, also in a quadratic format, but with a negative effect that is strongest at lower elevations. The presence of WET4 (wetness category=4) is questionable, given that the subcompartments are largely in Scotland, where the wetness categories only vary from 1 to 3. However, the coefficient on WET4 is plausible so we leave it.

Although R^2 values (Table 12) are not high, the crosstabulation (Table 13) shows that 24.2% of SC's were predicted correctly, with another 36.16% being only one YC misclassified. 18% of predictions are more than two classes incorrect, and some YCs (4, 22 and 24) were not predicted at all.

Table 12. Pseudo R-Square for Model (4).

Cox and Snell	.246
Nagelkerke	.249
McFadden	.066

Model 4. Northern Sitka

		Estimate	Std. Error	Sig.
Threshold	[YLDC = 2]	1.156	.386	.003
	[YLDC = 4]	1.718	.385	.000
	[YLDC = 6]	2.557	.384	.000
	[YLDC = 8]	3.345	.384	.000
	[YLDC = 10]	4.191	.385	.000
	[YLDC = 12]	5.249	.386	.000
	[YLDC = 14]	6.234	.387	.000
	[YLDC = 16]	7.253	.388	.000
	[YLDC = 18]	8.292	.390	.000
	[YLDC = 20]	9.483	.393	.000
	[YLDC = 22]	10.981	.411	.000
Location	AREAP	1.362E-02	.001	.000
	MINT	2.336E-02	.003	.000
	NORTH	-1.638E-06	.000	.000
	EAST	3.406E-05	.000	.000
	$EAST^2$	-4.849E-11	.000	.000
	ELEV	-4.491E-03	.001	.000
	$ELEV^2$	2.956E-06	.000	.010
	LAA	.219	.014	.000
	ROT1	-.465	.039	.000
	WET4	-1.096	.069	.000
	DEP1	-3.831E-02	.120	.750
	$DAMS^2$	-5.625E-03	.000	.000
	NORFACE	-7.743E-02	.025	.002

Notes:
LAA = natural log of AREAA
ROT1 = subcompartment in 1st rotation
WET4 = Soil wetness category = 4
DEP1 = soil depth category = 1
NORFACE = cos(ASPECT * pi/180) = north facing aspect

Table 13. Northern Sitka YLDC and Predicted Response Category Crosstabulation.

		Predicted Response Category									Total
		2	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	
YLDC	**2**	**11**	3	30	80	220	29	8			381
	4	18	4	20	53	149	10	1			255
	6	18	**19**	54	116	392	40	9			648
	8	15	6	**54**	134	679	101	30	2		1021
	10	11	6	34	**116**	1094	274	82	7		1624
	12	12	5	43	102	**1554**	621	240	14		2591
	14	4	3	27	61	1104	**767**	382	23		2371
	16	6	1	8	22	689	589	**461**	32	1	1809
	18	1	1	3	25	307	349	305	**28**		1019
	20	2		5	3	118	179	158	21		486
	22					37	61	76	9		183
	24					8	15	25	7		55
Total		98	48	278	712	6351	3035	1777	143	1	12443

4.5 Missing data

It is worth noting that only a relatively small number (5,362, or 7.24%) of Sitka subcompartments in the FC estate (74,054 SCs) lacked known yield class, and needed a predicted YC for this research. Even where YC was missing in the Sitka database, other variables used by Models 3 and 4 to predict YC were usually available in the FC records (SCDB). Only 71 sitka subcompartments had assumed rather than known SCDB variable values. The relatively high availability of known (rather than 'guessed') YCs, and variable values used to predict YC, in the Sitka spruce database should promote especially high confidence in our final valuations for this species (Tables 25-57.

YC was much more likely to be missing for oak and beech. 2960 (41.5%) of oak and 1604 (28.2%) of beech FC subcompartments had predicted rather than known YC. Missing data for the SCDB variables used to predict YC in these species was also common (699 oak and 197 beech records). YC had to be predicted for 56,420 ha (82% of total non-oak/beech area) of other broadleaves, but just 12,678 ha (4.45% of total non-sitka area) for other conifers in the FC estate. The high proportion of predicted (rather than field-measured) YCs for most broadleaf species is not optimal, and tends to suggest lower confidence in the final valuations.

4.6 YC Models Discussion

Tables 14 and 15 give total areas and percentage areas, by species or species group, where YC is known or predicted. The top half of each table notes the YC hectares and percentages of area where recorded in the FC SCDB; the bottom half of each table gives our model predictions. Comparisons are probably easiest to make by looking at the percentages under each YC for the known and predicted populations. Ideally, we would like the pattern of YC percentages in each predicted group to closely match the pattern for known YC percentages. What we observe in the model predictions is a tendency for central values to dominate, especially YC=12 for conifers.

For both beech and oak we find that the models tend to predict yield one class below observed YC values, with the bulk of predicted YCs about class below the observation group. Other FC broadleaves tend to be predicted as YC=6. Private broadleaf woodlands are more evenly balanced between YC 6 and 8, which is closely similar to the distribution for FC beech with known YC.

Almost 57% of sitka subcompartments without a known YC value are predicted to be YC 12, with another 28% having predicted YC=10 or 14. Similarly, other FC conifers also tend towards YC=12. Predictions for privately owned softwoods are somewhat higher than suggested by most of the FC conifers, with 88% of area in the range YC=12-16. This is in contrast to a fairly even spread of known YC values, mostly in the range 6-14, for all FC conifers (both sitka and non-sitka).

Table 14. Hectares (and percentages of total area) of known and predicted yield classes (from Models 1-2) for GB broadleaf woodland.

	Known Yield Class					
	2	4	6	8	10+	Total
Forestry Commission						
Beech	151	1527	5083	3821	499	11,081
	(1.36%)	(13.78%)	(45.87%)	(34.48%)	(4.50%)	(100%)
Oak	351	6343	3264	365	67	10,390
	(3.38%)	(61.05%)	(31.41%)	(3.51%)	(0.64%)	(100%)
Other broadleaf	1425	5251	3017	1435	1237	12,365
	(11.52%)	(42.47%)	(24.40%)	(11.61%)	(10.00%)	(100%)

	Predicted YC					
	2	4	6	8	10+	Total
Forestry Commission					0	
Beech	4.4	357	2607	472	5.5	3446
	(0.13%)	(10.36%)	(75.65%)	(13.70%)	(0.16%)	(100%)
Oak	4087	3508	587	6.4	0	8188
	(49.90%)	(42.84%)	(7.16%)	(.07%)		(100%)
Other broadleaf	1293	8877	36,797	8037	1416	56,420
	(2.29%)	(15.74%)	(65.22%)	(14.25%)	(2.51%)	(100%)
Private	1444	11,580	424,608	374,287	182,376	994,296
Broadleaves	(0.15%)	(1.16%)	(42.70%)	(37.64%)	(18.34%)	(100%)

Table 15. Hectares (and percentages of totals) for predicted yield classes (from Models 3 and 4) for GB conifer woodland.

Known Yield Class	2	4	6	8	10	12	14	16	18	20+	Totals
Forestry Commission											
Sitka Spruce	3311	2711	10,378	22,762	47,687	101,314	93,038	65,271	32,759	7671	386,902
	(0.86%)	(0.70%)	(2.68%)	(5.88%)	(12.33%)	(26.19%)	(24.05%)	(16.87%)	(8.47%)	(1.98%)	(100%)
Other conifers	5994	18,053	47,153	64,462	46,032	34,739	30,382	14,638	6073	4627	272,153
	(2.20%)	(6.63%)	(17.33%)	(23.69%)	(16.91%)	(12.76%)	(11.16%)	(5.38%)	(2.23%)	(1.7%)	(100%)

Predicted Yield Class	2	4	6	8	10	12	14	16	18	20+	Totals
Forestry Commission											
Sitka Spruce	335	0	78	822	1786	6792	1554	501	51	9.64	11,928
	(2.81%)		(0.66%)	(6.89%)	(14.97%)	(56.94%)	(13.03%)	(4.20%)	(0.43%)	(0.08%)	(100%)
Other conifers	157	0	43	385	1035	6364	1686	1205	268	1535	12,678
	(1.24%)		(0.34%)	(3.04%)	(8.16%)	(50.20%)	(13.30%)	(9.50%)	(2.11%)	(12.11%)	(100%)
Private conifers	12,898	129	3478	2197	15,916	200,947	252,516	352,751	69,878	3214	913,926
	(1.41%)	(.01%)	(0.38%)	(0.24%)	(1.74%)	(21.99%)	(27.63%)	(38.60%)	(7.65%)	(0.35%)	(100%)

We tried to improve the Sitka models by combining categories; e.g., YC 2-8 could all be treated as one YC category, and the same again for YC 18-26. These reduced number of categories of YC are referred to as YCRC. Using YCRC as the dependent variable resulted in a small improvements in McFadden R^2 values (i.e., from 0.066 to 0.075, and 0.085 to 0.091).

There is a difficulty in deciding how to treat these combined YC categories. There are significant increases in carbon storage especially between the upper YC values. The greater the error in YC estimates in these initial models, the greater the propagated error will be in subsequent carbon estimates. The conservative option is to treat all of the combined YC2-8 class as YC2, and YC 18-26 as 18. We plotted the predictions for YCRC or YC against observed YC values to compare model performance. The models using YCRC as the dependent variable provided a poorer match to the observed underlying YC values, than did the models that actually used YC as the dependent variable. In other words, by reducing categories, we would be creating a larger propagated error, and only for the sake of a modest increase in R^2 values.

The AREAA variable has a consistent positive effect on YC in most models i.e., the larger a subcompartment the higher its yield class. This may be due to better management of larger and potentially more valuable stands, with thinning, fertilising and felling occurring on schedule. Some species may modify the environment to their own advantage. It is also possible that larger stands see less intrusion by other flora.

We are aware that time-anchored predictors, such as planting year or survey date, are controversial in yield class models (Robert Matthews, pers. comm., 2002). A chief problem with such variables is that they may reflect a sampling bias – i.e., very productive sites are inherently likely to be felled and restocked early, leaving the incorrect impression that older stands tend to produce less timber than those planted more recently. The effect on our models is likely to be a small downward slant on carbon storage estimates in older woodland, with carbon storage in younger trees equally biased upwards. We are inclined to believe that the net effect of these opposing and small biases, aggregated over large areas and time, will be negligible. Additionally, a positive sign on planting or survey year variables could imply that productivity would continue to drift up indefinitely. For our purposes, however, YC is only assigned once, based on stand characteristics in 2001, so the “upward drift” problem should not apply.

Other carbon-storage researchers have tended to respond to the lack of known YC data for private holdings by assuming the same YC value for all conifer or broadleaf woodland in the UK (e.g., see Cannell and Dewar 1995; Milne *et al*. 1998). It may be argued (Robert Matthews, pers. comm., 2002) that management practices are likely to be more important with regard to woodland carbon storage than YC per se, negating the utility of considering YC on an individual stand basis. We conduct a sensitivity analysis to investigate this issue in Section 6.1.2. Unfortunately, due to lack of suitable data, we have to assume the same management regime (periodic thinning, felling date determined by economic criteria) for all timber stands.

Previous studies, including the researchers’ own have undertaken Yield Class models, usually using conventional regression techniques, and produced higher R^2 values than we report here. In previous yield class models for Sitka spruce (using OLS regression techniques), typical reported R^2 values were 0.368 (Macmillan 1991), 0.437 (Elston *et al.* 1997) and 0.428 (Bateman and Lovett 1998). Matthews *et al.* (1996) derived yield class models for nine species/species groups in lowland, southern Britain, using a variety of model forms in Ordinary Least Squares regression. The median R^2 value in their work was 32%, although values ranged from a low of 0.04 for Ash (*Fraxinus excelsior*), to a high of .60 for Corsican Pine (*Pinus nigra var. maritima*). The best R^2 statistics in their models for oak and beech were.31 and .43 respectively. The corresponding highest statistics in our models (Nagelkerke pseudo R^2) do not compare badly, at .341 and .269, although the more robust McFadden statistics are notably lower (.177 and .269). Sitka spruce productivity was not considered by Matthews *et al.* However, to directly compare the McFadden measure with conventional R^2's is not strictly valid, as the latter is calculated with inherent conservative biases. By empirical testing, Domencich and McFadden (1975) tended to conclude that a pseudo-R^2 value of 0.2 to 0.4 pseudo-R2 may be comparable to 0.7 to 0.9 for a linear function.

Overall, we feel that our yield class models are defensible, and too much emphasis should not be placed on the relatively low R^2 values. Our models produce plausible predictions that are quite similar to the distribution of YCs for known populations. We do use actual yield class values wherever possible.

5. Sequestration Models

The models used here are based on methodology developed previously in Bateman and Lovett (2000). That work calculated the total carbon stored in soils, trees and wood products, by species group (conifer or broadleaves), per hectare. The approach relied on underlying assumptions about carbon accrual in unthinned beech woodlands at YC=4, and Sitka spruce at YC=12. Sequestration rates were modelled using regression analysis on published data on the carbon gains in these species, both before and after thinning, from storage data in Cannell and Cape (1991) and yield data from Edwards and Christie (1981) on merchantable volume (MV). MV can be related directly to total carbon storage (Corbyn *et al.* 1988, Matthews 1991).

Bateman and Lovett described at length how felling and thinning dates were calculated, as well as the underlying assumptions regarding the rates of carbon storage and release. Optimal felling age was specified through use of the Foresty Commission Forestry Investment Appraisal Package (FIAP). FIAP operates by maximising the net present value of a stand subject to user-determined parameters, including tree species, yield class and discount rate. The FIAP output were input to regression analysis to derive a generalised model predicting the optimal felling date from just yield class and discount rate for each species. A regression equation to predict date of first thinning was similarly derived. It must be noted that models usually presume that every stand is being managed for optimal timber extraction value. This is obviously not always true; individual site managers may well apply other criteria to choose later (or earlier) felling dates. The availability of tax breaks and grants for woodland areas, as well as lack of formal training in forest economics, may tend to lead to later rather than earlier felling dates among small, private land owners. Similarly, it seems likely that some stands are being managed almost purely for amenity or existence purposes (e.g., ancient woodlands), rather than commercial considerations. Any criteria that tend to lead to later rather than earlier felling dates are especially important, because the carbon in trees remains largely unavailable to the atmosphere until felling. The net effect of adopting felling dates as calculated by FIAP is probably to introduce a downward bias in the carbon storage predicted by our models compared to reality.

We attempt to improve on the Bateman and Lovett (2000) work in various ways. The Bateman and Lovett models assumed that all subcompartments were in their first rotation, planted in 1991. Our revised models use the actual afforestation year, where known, or an estimate of likely afforestation year, using estimates of optimal felling dates at the given YC and discount rates, and (except for coppice) an assumption of no more than two rotations prior to the current planting. Carbon gains in live wood are assumed to stop when a rotation reaches the age of 300 years, but new gains in subsequent rotations are still possible. All carbon sequestered in soils, litter, live wood, and products, up to and including the year 2003 (base year) is given the full social value of carbon. Discounting (see Section 5.2) only occurs from the year 2004 onwards, until the year 3003, when final totals are noted. This long period should provide ample time to calculate net carbon sequestration over multiple rotations, harvests and restockings. The year 3003 is only used as a consistent endpoint, and is not meant to be significant in itself; our fundamental goal is to consider carbon sequestration for a (seemingly) infinite series of rotations into the future. In practice, the effect of discounting means that the value of carbon sequestered in the future tends to decline rapidly after 2003, and will certainly reach zero by the year 3003, except at unfeasibly low discount rates.

The models distinguish between three species groups in the FC estate, as well as other broadleaves and conifers on both FC- and privately-managed woods. Coppice and Christmas tree stands are also considered separately, due to their short rotation length and relatively quick release period. Except where PLYR values in the FC SCDB indicate otherwise, we assume that coppice trees are cut down every 12 years, with a release period of 22 years, of which 44% is within the first two years. Where otherwise unknown, coppice woodlands are presumed to have had nine previous rotations. We generally assume that Christmas trees are grown on a ten year rotation, with all carbon in live wood released in the first year after harvest. We assume 10,000 ha (see Section 5.4.2) of private woodland are in Christmas tree production. 10,000 ha may be an overestimate, and probably exerts a downward bias in our final calculations of sequestered carbon. We see this downward bias as acceptable, given that our goal is to produce lower-bound estimates of carbon stocks and their value.

Bateman *et al.* (2003) collected statistics on years from felling for 95% carbon releases from wood products for either hard or soft woods, given in Cannell and Cape (1991), and Thompson and Matthews (1989a,b). These release data are show in Table 16. Bateman and Lovett (2000) input these data to regression analysis, to derive generalised carbon release curves for conifer and broadleaf woodland respectively. See Bateman and Lovett (2000) for much more detail.

Table 16. Carbon release years post-felling for UK-grown timber.

Product	Softwood	Hardwood

	Modal liberation year (from felling)	95% carbon liberation (years from felling)	Modal liberation year (from felling)	95% carbon liberation (years from felling)
Sawn logs	70	150	150	300
Board	15	40[1]	15	40
Paper	1	5	1	5
Mining	40	200	40	200
Fuel	1	5	1	5
Other	15	30	40	80
Bark	1	5	1	5

Notes: 1. Based on this being almost exclusively particleboard as per statistics given in FC (1992). Carbon liberation sources: Cannell and Cape (1991) and Thompson and Matthews (1989a,b).

Harvesting and management of a timber site creates its own carbon emissions. Karjalainen and Asikainen (1996) observed annual harvest-related releases around 1.4% of the amount of carbon in harvested Finnish timber. Our model assumes that carbon releases from machinery and log transport for felling operations in the UK are slightly lower, at 1.25%, and occur entirely during the year of felling. In practice releases would be expected to occur steadily throughout the rotation, notably during thinning and planting. Also, Karjalainen and Asikainen only assessed primary silvicultural and harvesting activities, and did not include releases from processing or onward distribution of woody products. We have no reliable means of including these secondary carbon emissions in our models.

Work reviewed by Milne and Brown (2002) suggested that conifer woodlands in the UK accrue carbon in forest floor litter at an average rate of 0.25-0.32 t/ha per annum. Carbon in broadleaf forests appeared to accrue at an approximate rate of 0.24 to 0.28 t/ha per year. This deposition is not static, however. Milne *et al.* (1998) suggested that 50% of carbon added annually to litter is transferred into soils each year. At the same time, forest floor litter releases CO^2 back to the atmosphere at rates that may be accelerated by global warming (Richey *et al.* 2002). In contrast to this complex reality, our models treat carbon deposition in the forest floor quite simplistically. All trees of YC 14 on non-peat soils are assumed to deposit carbon into leaf litter at a net rate of 0.25 t/ha per year, for the first 100 years of afforestation. Thereafter, the models assume that an equilibrium state has been reached and no further net increases in litter carbon will occur. Accrual is directly proportional to YC14; i.e., a stand with YC=4 is assumed to accrue carbon into leaf litter at a rate that is 28.57% (=4/14) that of the accrual rate expected for trees of YC=14. The figures given earlier for net carbon flux on deep peat (Table 5) include carbon in leaf litter, and so no additional allowance is made for carbon gains on peat soils.

Our models do not assume that climate change will lead to greater carbon uptake in the future by faster growing trees. It had been postulated (see discussion in Delucia *et al.* 1999) that increased availability of carbon dioxide might cause trees to grow faster, taking up more carbon in the process. However, work by Hamilton *et al.*

(2002) suggests that the increased uptake will be no more than 10% of additional, anthropogenic releases per annum.

All the sequestration calculations and subsequent valuations were carried out using the Perl programming language (Christiansen and Torkington 1998) and spreadsheets working on the data files of yield classes and other attributes derived through the GIS (Arc/Info v. 7.2.1) and regression analyses. The models for Sitka spruce, beech and oak were used when these species could be identified in the FC database. Sitka models were employed for other conifers in the FC SCDB and the conifer category derived from the WI. The beech models were similarly used as a surrogate for other broadleaves.

5.1 Comparison with other carbon sequestration estimates

Comparisons are made to rates and sequestration totals estimated by previous authors. Cannell *et al*. (1996) implied per annum rates of 2.7 tC/ha per year for live wood *P. sitchensis* 25-40 years old, YC=14/16. Our model suggests gains of 2.4 tC/ha per annum. Cannell (1999) reported that a model of Sitka spruce, YC=16, felled at 55 years accumulated carbon in live wood, soil and litter at a rate of 3.6 tC/ha per year. We achieve the same felling date upon applying a discount rate of 3.8%. Assuming planting is on a upland soil (with possibility of gaining 50 tC in the first 265 years of afforestation), our model predicts an average per annum carbon sink of 3.5 t/ha. Our rates are fairly close to those of Milne and Brown (2002), who gave annual sequestration rates of 1.05-1.56 tC/ha for conifers, in national-level models. Using YC=8-14 and *P. sitchensis,* our model expects 1.15-2.17 tC/ha.

Dewar and Cannell (1992) estimated net sequestration in conifer trees and litter by yield class. They suggest per annum carbon uptake of 4.4, 4.1, 3.6, 3.0 and 2.4 (all tC/ha) for Sitka spruce, YC respectively = 24, 20, 16, 12 and 8. Using a discount rate of 3.9% we achieve the same felling dates suggested by Dewar and Cannell. Into live wood, our model suggests lower per annum first rotation C uptake, at 4.2, 3.6, 2.8, 2.1 and 1.3 tC/ha for the same YCs. However, some of these differences may be due to accounting for carbon into thinnings, which our models ignore (due to the short release period of their usual end use, paper). We estimate that carbon absorbed into thinnings could be in the range of .57 to 1.9 tC/ha per annum for YC=8 to 24. These additions would bring our live wood estimates much closer to those of Dewar and Cannell.

On a *P. sitchensis* site with YC=10-12, Hargreaves *et al*. (2001) report field studies that suggested live wood sequestration at 2-5 tC/ha per year, at ages 8-26 years. Our model predicts only 2.5-2.8 tC/ha/yr. However, our estimates of total carbon sequestration are above those of Cannell and Dewar (1995). They predicted that the long-term (after three rotations or so) equilibrium carbon storage in conifer trees and litter in GB would be about 75 tC/ha. Assuming YC=12-14, our models calculate long term carbon storage values of 61-68 tC/ha in live wood and 21-25 tC/ha in litter (non-peat soils), to produce a total of 82-93 tC/ha.

For sequestration in broadleaf trees, Milne and Brown (2002) predicted figures of 1.46-1.56 tC/ha per annum into live wood. During the first rotation, an oak stand with YC=4 was estimated by Dewar and Cannell (1992) to sequester 1.8 tC ha^{-1} yr^{-1} in trees, products, litter and soil. We use a discount rate of 3.95% to achieve the same rotation length (95 yrs). Assuming lowland planting, our model suggests first rotation oak sequestration rates (into live wood, soils and litter) of 1.88 tC ha^{-1} yr^{-1} for YC=4. Similarly, Dewar and Cannell estimated that beech woodland with YC=6 has first rotation C sequestration of 2.4 tC ha^{-1} yr^{-1}. Our model indicates 2.44 tC ha^{-1} yr^{-1}.

Cannell and Milne (1995) present estimates of carbon storage by age and tree species in Britain. For instance, they suggest that a 55 year old oak woodland holds 63.6 tC/ha in live vegetation, and that a 55 year old beech woodland holds 70.6 tC/ha in live vegetation. Our models predict 41-75 tC/ha for a 55-year-old, YC=2 to 4 oak woodland, and 59-83 tC/ha for the same age beech at YC=4 to 6. Patenaude *et al.* (2003) assessed carbon stocks at five semi-natural broadleaf woodland sites in south eastern England, producing esimates in the range of 346-616 tC/ha. This value includes livewood, litter, ground vegetation and soils. Subtracting an assumed 100 tC/ha for soils from the Patenaude *et al*. per ha figures brings them to 246-516 tC (i.e., in live wood, litter and ground vegetation). At YC=6 and all beech, our model predicts 379 tC/ha for a woodland at least 140 years old. This is nicely in the middle of the Patenaude *et al.* range.

We note that there is considerable variation in estimates of rates and totals between different studies. For example, Milne and Brown (2002) produced much lower estimates of per annum sequestration rates into conifers than those suggested by Dewar and Cannell (1992). However, in general, our models overlap well with the ranges of values indicated as sequestration totals and rates by other modellers and actual field measurements.

5.2 Social Value of Carbon

The "social value" of carbon sequestration can be defined as the benefit in savings from damage avoidance. This benefit is difficult to observe directly, but can be calculated by observation of compensatory costs to reveal its cost to society, or "shadow price". The lack of observable markets does introduce significant uncertainties in estimates of the true social cost of sequestered carbon.

We adopt three possible social values for each metric tonne (1000 kg) of sequestered carbon. Our working values are in US dollars, which we convert to GBP assuming a currency exchange rate of $1.5[3] per £1. Rather than the debate the merits of any particular carbon valuation, we consider three possible social values for carbon, at the high, medium and low end of the range of values previously proposed. The values increment year on year, based on expected increases over time in the magnitude of GHG-related damages. Values are held constant from 2031 because we cannot safely presume that this trend towards increased damages will extend indefinitely (e.g., scientific or technical innovations may mitigate harm caused by climate change). In a government working paper, Clarkson and Deyes (2002) argued the case for a relatively high value of £70 (US $105) per tonne of carbon, based on an equity-oriented analysis of climate change impacts by Eyre *et al*. (1999). We allow this to

---

[3] Historically, the exchange rate has been somewhat higher, at around $1.61 to £1 since 1990, but the mean daily US$ to GBP exchange rate from January 2000-May 2003 was almost exactly $1.50 (calculated by the authors, from data available on the US Federal reserve website, www.federalreserve.gov).

increment by 67 pence (\$1) per annum until 2031 when it plateaus at £88.67 (\$133). As a median value, our preference is for estimates by Fankhauser (1994, 1995), also cited by the Intergovernmental Panel on Climate Change (IPCC 1996). Fankhauser adopted a non-linear, stochastic model to examine future emissions, atmospheric concentration, radiative forcing, temperature rise, annual damage, costs of seal-level rise protection and discounting. Fankhauser's best estimate of expected damage equivalates at the end of 2003 to £14.70 (\$22.05), with increments of 16.7 pence (\$0.25) per annum until 2031, after which it stays at £19.37 (\$29.05). For sensitivity analysis, we also present a lower bound value, of £6.67 (\$10), which increments by 6.67 pence (\$.10) until 2031, stopping at a value of £8.53 (\$12.8).

5.3 Discount rates

With regard to the effects of climate change on people living today, carbon sequestered today has more value than carbon locked up tomorrow, which in turn is worth more than carbon sequestered in the distant future. This is analogous to the idea that money in hand today is worth more than money in hand tomorrow. The decline in present versus future value is a fundamental economics concept, formalised as a *discount rate* (Price 1993). In practice, discounting can simply be a multiplier on notional carbon values, calculated by the following formula:

$$V = 1/(1+r)^n$$

Where V = value in base year terms
r = discount rate (as a decimal, so 6% would make r = .06).
n = years since base year.

For instance, using 2003 as our base year, a discount rate of 6% means that the value of carbon sequestered in 2004 has 94.34% the value of carbon sequestered in 2003. Carbon sequestered in 2005 is worth 89% of the 2003 value, etc. Clearly, the larger the discount rate the more rapid the decline in the value of future carbon sequestration, and even small discount rates have significant cumulative impact on carbon values. Even with a relatively modest discount rate of 3.5%, carbon sequestered in the year 2103 (one hundred years after the base year of 2003), will only have 3.21% the value of carbon sequestered in 2003.

Three discount rates are applied in this study: 2%, 3.5%, and 6%. 2% reflects work by Arrow *et al*. (1996) with regard to discount rates for climate change. 3.5% is the revised UK Treasury Green Book discount rate for public sector projects with social benefits from 2003; 6% is the previous Treasury Green Book discount rate.

5.4 Caveats

5.4.1 Peat Soils

Carbon release rates on thin peat soils have not been well studied, and our assumptions about releases from these soils may be especially unreliable. Taylor (1983) gave summary statistics to the effect that 1.360 million ha in Great Britain are deep peat soils; our data suggest a figure of 1.342 million ha for deep peat. We have no statistics to confirm the areal extent of thin peat soils, however.

Field observations (Hargreaves *et al*. 2001) indicate that woodlands on peat soils may enter into renewed periods of carbon fixing during the early years of each rotation, but our models do not allow for this. We assume that per annum long term releases on thick or thin peat soils are constant at 0.3 tC/ha, until the total expected carbon loss is realised. Thus, a presumed total end loss of 750 t/ha per annum would require almost 2500 years to complete. As a result, while we indicate that our models allow for cumulative losses up to 750 tC/ha, in fact, this total is very unlikely to be realised within our time frame (before the year 3004).

We attempt a brief sensitivity analysis addressing some of these points in Section 6.11.

5.4.2 Christmas trees

The British Christmas Tree Growers Association (BCTGA, Roger Haye, pers. comm., 2002) provided basic statistics about how much private woodland was in Christmas tree production. At an expected stocking density of 5,400 trees/ha, and an assumption that 65 million Christmas trees are growing in the UK in 2003, we expect 5,900 ha to be in private Christmas tree production. If the stocking spacing drops to 1.7m, however, this would suggest 13,900 ha of Christmas trees outside the FC estate. Although the BCTGA cited a one metre spacing as standard for Christmas tree growers, 1.7-2.0m was overwhelmingly typical on the FC estate. Moreover, the BCTGA acknowledge that some crops are managed more like a conventional conifer plantation, in that small Christmas trees may be thinned for domestic use, and larger specimens left to grow and sold at a later date for public displays. We opted for a compromise value of 10,000 ha. This figure may be excessive, in which case it will exert a downward influence upon the total carbon stocks suggested by the study. As the locations of the actual plantations are not known, we had to randomly assign young conifer or mixed species areas in the Woodland Inventory to the Christmas tree crop. We placed 60% in Scotland (of the assumed 10,000 ha), and 40% in England and Wales, among the young trees (feature code = 85) category in the Woodland Inventory.

5.4.3 Felling dates

It is worth recalling that our models usually presume stands are managed for optimal timber extraction, with thinning and felling dates indicated by the FIAP software. In reality, many broadleaf woodlands will not be managed with such commercial considerations foremost. Unthinned or delayed-thinning woodlands, or those left standing well beyond their optimal (in terms of market value) felling date, hold significantly more carbon than sites that are regularly felled.

The models calculate an optimal felling (F) and first thinning dates, using formulae in Bateman and Lovett (2000). Many FC stands, however, are older than our estimate of their optimal F. In such cases, if a subcompartment is in its first rotation, we assume that the felling will occur in the year 2004, and that future fellings will occur when the stand is at our calculated optimal F value. Christmas tree and coppice stands are given a single F value for all rotations, this being the greatest of 10 years (Christmas tree), 12 years (coppice), or 2004-current planting year.

As a result, the model attempts to allow for FC subcompartments that are being managed by criteria other than strictly economic (e.g., as ancient woodland). However, we lacked information (i.e., known PLYR values) to handle non-FC woodland as precisely. Our identification of ancient woodland (Section 3.2) was crude. Where the condition on a possible ancient woodland site was deemed 'poor' or 'unknown', we presumed that the site was planted in 1874, with trees therefore 129 years old in the year 2003. Our models would over-estimate carbon stores if the trees on these sites were actually felled between 1874 and 2003. We try to counter this potential bias by treating such 'unknown' stands as a first rotation, making no allowance for carbon storage associated with those sites prior to 1874, and felling the trees (in our model) in the year 2004. These assumptions may be too conservative, or too generous.

5.4.4 Carbon in woodland products

At present, the models consider sequestered carbon in wood products from woodlands felled both in the past and future. It is defensible to argue that the carbon locked up in products from timber felled as recently as 1999 or 2000 should be included. However, it may be less credible to include carbon in timber products created 50 or 100 years ago and include this as part of the carbon currently in the FC estate and all GB woodland. For instance, it is worth considering that the models for conifer forest assume that 20% of carbon is still sequestered and valued as late as 121 years after felling. We are confident in our lifetime analysis of carbon release periods from woody products (see Table 16 from Bateman and Lovett 2000), but note that our release periods are much longer than those adopted by other modellers. For instance, Matthews and Heaton (2001) assumed that all carbon would be released from wood products within 50 years. Cannell and Dewar (1995) assumed that 100% release periods were roughly equal to rotation lengths (typically 50-70 years). Use of these much shorter release periods would significantly revise our model estimates downwards.

5.4.5 Other Greenhouse Gases (GHGs)

This research confines itself to the impact of carbon sequestration on global warming. We take no account of forestry or soil greenhouse-gas emissions other than carbon/carbon dioxide. We acknowledge the importance of these other GHGs when assessing the net impact of GB forestry on global warming. Of particular importance is the role of peat soils as a sink or source of the other main GHGs, methane (CH_4) and nitrous oxide (N_2O). Although smaller in sheer volume of releases, these GHGs have immense potential to alter climate. The global warming potential (GWP) of methane is roughly 21 times as high as carbon dioxide, nitrous oxide has about 300 times the GWP of CO_2. Undisturbed peat is generally a net source of methane emissions, while disturbed peat is likely to become a methane sink. Whilst many soils have been observed to emit N_2O, drained peatlands are noted as particularly important sources (Leffelaar *et al*. 2000; Chapman *et al*. 2001). The trade-off between carbon dioxide and methane emissions caused Cannell *et al*. (1993) to treat peat soils, undisturbed or otherwise, as GHG neutral. However, Kasimir-Klemedtsson *et al.* (1998) calculated that for Finland, at least, undisturbed peat bogs are net emitters of GHGs.

The picture is complicated by nitrous oxide and related NOx emissions from routine forestry operations; i.e., from thinning, harvesting and milling machinery. Moreover, climate change (including warmer temperatures and higher atmospheric concentrations of CO_2) may increase timber yields and the rate of carbon uptake in living trees, as well as nitrogen deposition in GB woodlands (Murray *et al.* 2002). All such considerations of possible increased tree growth, increased nitrogen deposition and N_2O or methane budgets were beyond the remit of this study.

5.4.6 Other issues

Official Forestry Commission statistics (FC 2001a) state that 801,000 ha of GB woodland are managed by Forest Enterprise. Subcompartments with a tree species code in the SCDB supplied to us by the FC only sum to around 735,000 ha. We have no explanation for the discrepancy. FC (2001a) also gives definitive statistics on the percentages of private woodland devoted to conifer or broadleaf trees, estimates that we understand were based on sub-samples of the WI data. Our version of the WI does not readily facilitate such definitive assessments, in that the WI often designates an area simply as “mixed” woodland. However, we have tried to adopt the FC (2001a) proportions to assign private woodland SC’s as either broadleaf or conifer. These assignments may not yield close approximations of the true species proportions in each of the FC conservancies for which we make regional totals in our final results. Our assignments suggested a GB total of 912 kha and 993 kha respectively in privately-held conifer and broadleaf trees. FC (2001a) gives figures of 876 kha (conifer) and 1030 (broadleaf) kha for non-FC managed woodland.

We assume that yield class values, rotations, management regimes and likely felling dates are the same for FC and private holdings. We predict YC for coppice and Christmas trees using models developed for pure beech and Sitka plantations (managed as timber stands). These may not be reliable model transfers.

The use of just a few generalised planting years and assumed rotation values is not ideal. Alternatively, planting year and rotation assignments could have reflected a continuous distribution of likely values.

The research fails to consider individual trees or small groups of trees, especially in urban areas, and their carbon sequestration potential. The Woodland Inventory omits areas of woodland under two ha. It is believed that about of 5% of GB woodland, in addition to isolated trees, are omitted from the WI. The carbon storage in these micro-woodlands, urban and isolated trees could be significant in some localities (e.g., South East England, West Midlands).

We do not consider the carbon in other types of vegetation, or the carbon in undisturbed peat in the FC estate. We are interested in the specific carbon storage potential of woodlands as opposed to other non-urban land uses. However, Patenaude *et al.* (2003) reported that understorey vegetation in five broadleaf woodland sites averaged 18 tC/ha. Cannell and Milne (1995) gave generic figures of 2-11 tC/ha for agricultural and non-woodland vegetation cover in the UK. Subtracting the Cannell and Milne values from Patenaude *et al.*’s figures, suggests that 7-16 t/ha more carbon may grow in understorey woodland than might exist under other rural land uses, and therefore rightfully could have been included in our assessment.

Adger *et al*. (1992) argued that the mixture of planting upon peat soils and the replacement of old growth broadleaf woodlands with conifer plantations had resulted in post war forestry being a net emitter of carbon. We lack the historical data to confirm this assertion.

The models assume that the species and management regime (i.e., high plantation, Christmas trees or coppice) observed in a subcompartment now is the species/regime that has previously been and always will prevail there. This is obviously unlikely to be true in reality. For instance, many currently conifer subcompartments in lowland Britain were probably deciduous until at least the middle of the last century. Moreover, land in GB has tended, historically, to pass in and out of woodland. We lack the data to thoroughly model for these fluctuations in historical land use. Market forces and competing land use priorities are likely to cause the percentage of woodland cover in Great Britain to fluctuate in the future, as well. The choice of planting species, and management regimes, also seem likely to change with different social, political and economic priorities.

A significant proportion of coppice products is firewood, primarlily used for domestic purposes (cooking and heating). Crops raised for such 'biofuel' purposes have the additional benefit of preventing carbon release from the combustion of fossil fuels that might othewise be have been used. Marland and Schlamadinger (1997), Marland *et al.* (1997) and Gough *et al*. (2002) discuss the potential of biofuel crops to mitigate global warming. A more ambitious assessment than ours might attempt to include this benefit. Given the small extent of coppice woodlands in the UK, however, this omission probably had negligible effect on our final valuations.

Many if not most private broadleaf woodlands are less densely stocked than the FC estate. This makes it likely that the 1.7m spacing used here (see Section 3.2) is too low. We lack information on what a more representative value might be. An assumption of too low spacing in the private broadleaf estate would serve to raise our yield class predictions (Models 1 and 2). For instance, doubling the spacing (from 1.7 to 3.4) tends to lower predicted YC by two yield classes (although no YC will be predicted below 2). Thus, our estimates for carbon storage in the private broadleaf estate could be distorted upwards.

6. Results

Final social carbon values are presented as three tables for each government office region (GOR), in alphabetical order: Eastern England, East Midlands, North East England, North West England, Scotland, South East England, South West England, Wales, West Midlands, Yorkshire and Humberside. There is one table for each social value of carbon, with columns for the three possible discount rates. Rows indicate the value of carbon stored now and in the future for separate soil types on FC and WI categories, with summary totals at the bottom of each section. There are three final tables giving the total social value of carbon for all of Great Britain, by management, species and soil type.

Values are expressed as net present values (NPV), in millions of pounds sterling. We would have preferred to list annuities (per annum benefits). However, there are several difficulties in so-doing. Carbon sequestration, unlike other forest benefits, changes in value over time. Specifically, carbon is sequestered faster in early rotations than in later rotations, resulting in a benefit stream that is inconsistent over multiple rotations. Application of standard annuity formulae (Price 1989) would result in over-estimates of per annum benefits for all crops afforested relatively recently. The errors would probably be small, but we cannot see an easy method for circumventing this problem to produce reliable annuity equivalents of NPV.

From Tables 25-57, it becomes apparent that the carbon stored currently in live wood and soils dominates the results. The total values per hectare are mostly dependent upon the carbon stocks in trees already standing in 2001, with subsequent growth providing relatively small adjustments to the final NPVs. Consequently, values do not vary greatly with increasing discount rates (i.e., from left to right in each row of each table).

Even at the highest discount rates (6%) and the lowest social value (£6.67), the tables suggest that the carbon sequestered in Great Britain's trees is worth at least £1.7 billion. Table 17 summarises the valuations using the median social value of carbon (£14.70 in 2003) and discount rate (3.5%). The total value of carbon under these assumptions is £5.92 billion. Almost one half of the carbon value (£2.6 billion) in GB woodlands is in Scotland. The lowest values are observed for the North East GOR (just £190 million). Apart from Scotland, there is a trend for carbon stocks to rise as one moves southward, with the South East GOR having the second highest values after Scotland, and the South West GOR and Wales next highest. This might seem surprising given the high stocking levels in Northern England. However, southern woodlands tend to contain older, broadleaf trees in later rotations, versus relatively young, first-rotation and conifer plantations in the north. Moreover, much of the stock in Northern England tends to be on peat or upland soils, which have reduced or even negative carbon sequestration potential in our models.

Overall, private woodland has nearly three times the carbon sequestration value of the FC estate. Much of this is due to ancient woodlands, as well as less private planting on peatlands. The value of carbon held in private broadleaf woodland in England is especially significant (£1.8 billion). This is greater than the carbon sequestration value of the entire FC estate in Great Britain (£1.6 million).

With respect to the area they occupy, deciduous trees hold a disproportionate share of the carbon compared to conifers. This is illustrated in Table 18. The greater values for broadleaf forests are primarily due to later felling ages for broadleaf trees, as well as infrequent planting of deciduous species on peat soils. It should be emphasised that the differences are not truly dependent on species type (see Section 6.2). Low carbon sequestration NPVs for conifer woodland is due very much to their relative youth, and to *where* trees are planted, not what kind of trees they are.

It was unrealistic for us to model and present results with full confidence intervals for each species/management group listed in Tables 25-57. We can, however, make some general comments on the reliability of our final valuations. We prefer that our results be conservative, lower-bound estimates. Accordingly, as described in previous sections, the models generally have downward biases in calculating sequestration rates. The accuracy of the sequestration rates, in turn, is probably most strongly linked to assumptions about planting year, length of rotation, yield class and carbon releases on peat soils. We have the most confidence in our yield class assignments for Sitka spruce, less for other FC species, and can least rely on our YC assumptions for private woodlands. It seems likely that our level of confidence in the valuations presented in Tables 25-57 should be corresponding. However, the frequent planting of conifers on peat soil sites, and the uncertainties around the pattern of carbon releases for planting on such soils, reduces some of the confidence that we might otherwise have in all conifer results. We have had to make rotation assumptions (both the duration and initial planting date) for all of privately managed woodlands. Our identification of ancient woodland sites was somewhat crude, but it is hard to ascertain whether we have generally over- or under-estimated sequestration for this type of woodland. Even in the FC estate, subcompartment records did not always give complete information on current planting date or rotation. Where such data are available (as for most FC subcompartments, and especially Sitka spruce), our estimates are probably most reliable. Otherwise, we have tried as much as possible, to bias the calculations towards producing conservative values.

Table 17. Regional total NPVs (£ millions), for 3.5% discount rate and 2003 social value of carbon = £14.70

		Forestry Commission		Non-FC	
	Totals	Broadleaf	Conifer	Broadleaf	Conifer
Eastern England	300	7	46	200	47
East Midlands	190	11	14	140	24
Northeast England	153	4	84	56	71
Northwest England	315	4	120	126	66
Scotland	2,618	39	830	487	1,262
Southeast England	730	46	33	564	86
Southwest England	568	23	46	394	104
Wales	580	20	219	236	106
West Midlands	241	6	15	172	48
Yorkshire and Humberside	223	5	25	136	58
Totals	5,918	166	1,431	2511	1,871

Table 18. Per hectare mean social value carbon sequestered in GB woodland

	NPV (£/ha)
FC beech	2250
FC oak	1629
FC Sitka	2311
FC other broadleaf	1409
FC other conifer	1414
WI broadleaf	2353
WI conifer	1996
Broadleaf average	2280
Conifer average	1973
GB woodland average	2098

Notes: FC=Areas managed by Forest Enterprise on behalf of Forestry Commission, WI=Other woodland identified from the Woodland Inventory (i.e., non-FC, or "privately" managed forests).

6.1 Sensitivity analysis

It is unlikely that all of the assumptions used in this work are optimal. This point is especially true with respect to the expected losses of soil carbon on afforested peat. Questions marks could also be raised over the assumptions about whether yield class modelling is necessary, or if a universal average YC value can be used with only small errors in final carbon valuations.

6.1.1 Cumulative C losses on peat, and loss of the annual peat sink

Table 19 gives some indication of the effect of our assumptions about the rate of carbon emissions from afforested peat on final NPVs. The table shows the estimated per hectare value for a peat soil afforested with Sitka spruce, YC=10. Although YC=12 is a typical median YC value for Sitka spruce nationally, productivity tends to be lower on peat soils (Hargreaves *et al*. 2001). A discount rate of 3.5%, and the median social value of carbon (£14.70 per tonne, in 2003) are applied. Results are otherwise given for one hectare planted in Sitka spruce, first planted in the given year, and with the indicated assumed long term total carbon losses per hectare, following afforestation. The losses actually used in our models are included (i.e., 750 t/ha for "thick" peat, and 112 t/ha for "thin" peat), as well as alternatives. Recall that undisturbed peat at high latitudes is generally believed to act as a net carbon sink. Column (iv) in Table 19 shows the expected sink loss for associated cumulative losses (e.g., 0.25 tC ha^{-1} yr^{-1} for 750 tC/ha, or 0.0373 tC ha^{-1} yr^{-1} for 112 tC/ha). We also consider a faster rate of loss, at 0.5 tC/ha/yr (but the same cumulative loss of 750 tC/ha).

At a 3.5% discount rate, the value of carbon stored or released declines to less than £0.01 (one penny) per hectare, in the year 2208. Using the carbon decay rates suggested by the Centre of Ecology and Hydrology models, only a maximum loss of 75 tC/ha on peatlands could be expected in the period 1935-2208, from a peat site first drained for afforestation in 1935. Thus we establish that our model assumptions about cumulative total carbon losses (i.e., 750 or 112 tonnes) on afforested peat are fairly unimportant (unless evidence arises to suggest that the cumulative losses would be much less than 75 tonnes/ha). Rather, virtually all of the variations in the values in Table 19 are due to the role of peat as a carbon sink – i.e., the 0.25 tC/ha that the model assumes a deep peat bog fixes each year (see Section 5). Recall that the model ends this potential sink in the year 2021, however. As discussed previously, there is evidence to suggest that peat bogs lose their carbon accrual function in warm years, and that bogs even tend to become net C emitters in very warm years. Temperature increases large enough to cause British peat bogs to lose, if not reverse their function as carbon sinks, are feasible by 2021. The strong effect of this lost sink in our value calculations therefore raises an interesting question. What if temperatures in Great Britain rise enough to cause most peat bogs to stop absorbing carbon, or even start emitting it, by the year 2021? The loss of the 0.25 t/ha sink has large impacts in our model, and supports the principle that peat soils should not be afforested -- currently. If the sink should disappear or even reverse by 2021, a reanalysis of the situation might lead to very different conclusions. If nothing else about afforestation should prove to accelerate peat carbon losses, would more carbon be fixed and greater social benefits be generated, at least in the short run (after the year 2021), by afforesting undisturbed peat? We are not yet in a position to produce an answer to this question, but it is an important possibility to consider.

Our sensitivity analysis therefore concerns itself not so much with cumulative carbon emissions on afforested peat, but rather the loss of the existing sink. Column (iii) in Table 19 gives the percentage variations in final NPVs due to changes in lost sink, between the expected lost sink of 0.25 versus 0.1 or 0.5 tC ha^{-1} yr^{-1}, and 0.0373 versus 0.0167 tC ha^{-1} yr^{-1}. From the FC subcompartment database we know that the majority of Sitka spruce is in its first rotation, with a median planting year of 1970-1971. 1971 may be the best year on which to try to make general statements about the uncertainties in our peat calculations. In 1971, NPVs rise by 13% if we assume a lost annual sink of 0.1 tC/ha rather than 0.25 tC/ha. The corresponding percentage gains in NPV for 1935, 1953 and 1989 are respectively 25%, 18% and 9%. Turning to thin peat, NPVs rise by only 1.54% if we assume 0.017 tC/ha rather than 0.0373 tC/ha as the missing annual sink for initial plantings in 1971. The corresponding percentage gains in NPV for 1935, 1953 and 1989 are respectively 2.9%, 2.1% and 1.2%. These last changes are small enough to imply that the model inclusion of an on-going sink on thin peats was possibly unnecessary. However, if a lost annual sink of 0.5 (rather than 0.25) tC/ha were assumed for deep peat soils, NPVs drop by £162 to £460 per hectare. The percentage decrease ranges from 15% to almost 42%. If mean annual carbon accumulation on "thin" peat truly is less than or equal to .0373 t/ha, then our model predictions are probably still quite reliable (as lower bound estimates) on these soils. However, upward or downward revision of the usual carbon sink on deep peat could alter our calculations on these soils considerably.

Table 19. Effect of varying carbon loss totals for peat soils afforested with Sitka spruce, allowing for given planting years, on Net Present Value (£) calculations (per hectare).

(i) Expected Cumulative C loss (tC/ha)	(ii) NPV in 2003 £/ha	(iii) Gain/Loss in NPV if 0.0167 assumed instead of 0.0373, or 0.1/0.5 assumed instead of 0.25	(iv) Assumed magnitude of lost carbon sink (tC ha^{-1} yr^{-1})
Planting year = 1935			
50	1537	2.88%	0.0167
112	1494	--	0.0375
300	1379	25.02%	0.1
750	1103	--	0.25
750	643	-41.70%	0.5
Planting year = 1953			
50	1539	2.12%	0.0167
112	1507	--	0.0375
300	1417	18.08%	0.1
750	1200	--	0.25
750	840	-30.00%	0.5
Planting year = 1971			
50	1454	1.54%	0.0167
112	1432	--	0.0375
300	1366	12.99%	0.1
750	1209	--	0.25
750	947	-21.67%	0.5
Planting year = 1989			
50	1229	1.24%	0.0167
112	1214	--	0.0375
300	1174	9.11%	0.1
750	1076	--	0.25
750	914	-15.06%	0.5

Notes: Assumptions are: YC=10, first rotation, discount rate = 3.5%, Social value of carbon in 2003 = £14.70 (with increments to year 2031 as noted in Section 5.1). Sequestered carbon is valued from the years 2003-3003 inclusive. Assume annual C uptake on undisturbed peat prior to planting as noted in Column (iv).

6.1.2 The effect of YC variations on carbon valuations

Milne *et al.* (1998) undertook sensitivity analysis of varying yield class when modelling carbon uptake by Great Britain's forests. They concluded that varying YC between classes 10-16 only resulted in changes of 10% (plus or minus) in total carbon storage in conifers. Subsequent work by the same authors has tended to therefore adopt median YC values (i.e., YC=12 for Sitka spruce, and YC=6 for beech) when assessing carbon stocks. It might be argued that the same generalised approach should be used when calculating the social value of carbon sequestered in GB woodland. We assess this issue on a single stand basis, for both Sitka spruce and beech, as shown in Table 20.

The top half of Table 20 shows the estimated per hectare value of carbon sequestered in Sitka spruce, yield classes = 8-18, planted in the years 1935, 1953, 1971 and 1989. A discount rate of 3.5%, and the median social value of carbon (£14.70 per tonne, in 2003) are adopted. We assume a possible cumulative soil carbon gain of 50 t/ha (upland planting). Results are otherwise given for one hectare first planted in the given year. Table 20 shows similar calculations for beech woodland, but assuming a cumulative gain in soil carbon of 100 t/ha (lowland planting).

Table 20 shows considerable variations between valuations for different Sitka spruce yield classes. YC=16 has valuations 21-23% higher than YC=12; a stand with YC=12 has social carbon sequestration values about 30% higher than those for YC=8. If the valuations are averaged between YC=16 and YC=8, however, they are very close to the YC=12 valuation. For instance, in 1935, the mean of £5005 (YC=16) and £3128 (YC=8) is £4067, which is nearly equal to £4078 (the 1935 NPV for YC=12). The majority (9%, Table 15) of the FC estate is in these yield classes (YC=8 to 16). As long as we can be sure that YC=12 is a true median, with yields equally distributed around this median, then it would appear that the use of a single YC value is valid for Sitka spruce.

Variations in carbon valuations are similar for broadleaf YCs (lower half of Table 20). For instance, a stand has a value 20-25% higher if YC = 6 rather than YC = 4. However, in percentage terms, if the valuations for YC=6 and YC=2 are averaged and compared to the valuations for YC=4, the percentage differences (from the YC=4 value) are less than 1.5% for all example years. From Table 14 we know that the majority of FC broadleaf woodland has yield classes 2-6. Similarly, we can average valuations for all broadleaf YC=2 to 10, in each year, and compare to a proposed median value of YC=6. The single calculated value for YC=6 is only 0.6-1.2% higher than the averages for all YC in the same year.

The case for using a median YC value, when assessing the value of carbon sequestration among Great Britain's woodlands is quite tenable – on a gross scale. It is essential that a true median value be used, however. Use of a single YC is also only credible provided that it can be verified that there is an even distribution of YC values around the median. For very small or very large study areas the assumption of a single YC value comes more into question. It is important to recall that timber productivity varies markedly across Great Britain (Matthews *et al*. 1996). If a single YC value were used for carbon valuations across GB, it seems likely that any regional estimates would be incorrect – even if national calculations were reasonably reliable. The use of regional medians for YCs (e.g., Milne *et al*. 1998), when data are being summarised for those same regions, seems defensible, however.

Table 20. NPV calculations (£/ha) allowing for variations in yield class

Sitka spruce

Planting year	YC=8	YC=10	YC=12	YC=14	YC=16	YC=18
1935	3128	3608	4078	4534	5005	5460
1953	2916	3390	3839	4263	4687	5083
1971	2631	3032	3414	3780	4153	4500
1989	2184	2504	2807	3094	3386	3647

Beech

Planting year	YC=2	YC=4	YC=6	YC=8	YC=10
1874	3022	4080	5094	6076	7045
1924	2895	3835	4678	5467	6255
1974	2384	3065	3680	4252	4811

Notes: Assumptions are: First rotation planted in given year, discount rate = 3.5%, Social value of carbon in 2003 = £14.70 (with increments to year 2031 as noted in Section 5.1). Sequestered carbon is valued from the years 2003-3003 inclusive. Assumed cumulative soil carbon increase is 50 t/ha for Sitka spruce, and 100 tC/ha for beech.

6.2 Future plantings

Thus far, we take no account of future planting on sites previously not in woodland. Bateman *et al.* (2003) note that by the year 2000 new afforestation appeared fairly constant in Great Britain, at around16,000-18,000 ha/annum, figures also suggested for 1996 by Milne *et al*. (1998). The Forestry Commission (FC 2001a) gives new planting figures in 2000-2001 as shown in Table 21. Virtually all new plantings were private (non-FC). Continued new afforestation at this level could make significant increases to carbon stocks. We lack more specific information on where the new plantings are, upon which soils, and we cannot be sure that this level of new plantings will continue for all of the next millenium. We therefore present estimates of the value of these new plantings based on plausible assumptions. We assume that the proportions and levels in Table 21 will persist through to the year 2203.

From the FC SCDB we make the observations shown in Table 22 about the proportion of planting on different soil types. In spite of the undesirability of new planting on peaty soils, and policy to discourage such planting by the FC, map overlays by Chapman *et al*. (2001) found that 70% (3180 ha/yr) of new private afforestation in Scotland that was subsidised by the FC-funded Woodland Grant Scheme (1988-2001) occurred on deep peat soil. 75% of planting in the period 1994-2001 was on deep organic soils – i.e., peat. A further 21.3% of afforestation during this last period occurred on soils that might be categorised as thin peat. Similar to our analysis, the work by Chapman *et al*. relied on mapped soil data on 1x1km grids. Thus, the actual soil type for many individual WGS sites may have been different from the predominant soil type of the 1x1km grid square that each WGS site fell into. Nevertheless, the Chapman *et al.* analysis suggests that many if not most new plantings under the WGS are on peaty soils. This occurred in spite of the opportunity that the FC had (with respect to approving the release of funds under the WGS) to discourage planting on peat. Disincentives for peat afforestation undertaken outside the WGS seem likely to be fewer. New woodland creation on wetlands by the FC is certainly declining, however, and this may be reflected in the private sector (eventually). Our own overlays of the Soil Survey digital soils data and FC Sitka spruce subcompartments suggest that about 10.8% of FC subcompartments newly created 1990-2001 were on deep peat soils, and 59% on thin peat soils. Recent figures, for just 2001, suggest that only 5.6% of new FC plantings were on deep peat, and 25% on thin peat.

Table 23 presents one scenario for beech, and two for Sitka spruce, to produce estimates of the future value of carbon sequestration in GB woodlands until the year 2203. Table 21 is used to calculate expected ha of future plantings in different parts of the UK. Plantings of beech are expected to continue to follow current proportions for soil types (Table 22). Future planting of Sitka spruce may follow recent trends (post 1980 in Table 22), but Table 23 also considers a scenario where no new planting of Sitka Spruce occurs on any peat soils. Instead, new planting is expected to be 80% on upland non-peat soils, and 20% on lowland non-peat soils. In Table 23 a discount rate of 3.5% is applied to determine felling and harvesting dates. Carbon stocks are valued at our median social value (£14.70/tC). Otherwise, all conifer planting is assumed to be Sitka spruce, YC=12. All broadleaf planting is assumed to be beech, YC=6.

Table 21. New GB planting (‘000 ha) in 2000-2001

Species group	England	Scotland	Wales	Total GB
Broadleaf	5.2	7.8	0.4	13.4
Conifer	0.7	3.9	0.1	4.7

Source: FC (2001a)

Table 22. Percentages of existing (in 2001) FC and WI subcompartments planted on different soil types

	Lowland non-peat	Upland non-peat	Thin peat	Thick peat
All beech	55.8	33.3	10.7	0.28
First rotation Sitka spruce	7.8	16.6	64	11.6
First rotation Sitka spruce planted after 1980	3.5	10.5	68.5	17.5
All FC broadleaf	47.9	25.49	24.93	1.68
All FC conifer	12.32	15.53	60.07	12.07
All WI	43.88	16.3	34.67	5.15

Source: From map overlays made by the authors.

Table 23. Net Present Value (£ millions) of new planting 2002-2202.

Beech				
	England	Scotland	Wales	GB totals
Lowland non-peat	236.03	354.05	18.16	608.24
Upland non-peat	103.70	155.55	7.98	267.23
Thin peat	17.10	25.64	1.32	44.06
Thick peat	0.44	0.65	0.03	1.12
All beech	357.27	535.90	27.48	920.65
Sitka spruce, some planting on peat				
	England	Scotland	Wales	GB (totals)
Lowland non-peat	2.13	11.89	0.30	14.33
Upland non-peat	4.91	27.35	0.70	32.96
Thin peat	16.69	93.01	2.38	112.09
Thick peat	4.28	23.83	0.61	28.72
All Sitka spruce	28.01	156.08	4.00	188.10
Multispecies totals, with some SS planting on peat	**385**	**692**	**31**	**1109**
Sitka spruce, no planting on peat				
	England	Scotland	Wales	GB (totals)
Lowland non-peat	12.33	68.71	1.76	82.81
Upland non-peat	37.29	207.79	5.33	250.41
All Sitka spruce	49.63	276.50	7.09	333.21
Multispecies totals, no SS planting on peat	**407**	**812**	**35**	**1254**

Note: Discount rate = 3.5%, social value of carbon = £14.70/tonne.

Table 23 indicates the social value (NPVs) of new plantings after the year 2001. The data are broken down by region, into Wales, Scotland and all England. These sums could realistically be added to Tables 17, 38, 47 and 56 to give total valuation of carbon stocks in Great Britain. Gains are in the region of 19% of current NPVs (i.e., the totals in Tables 17, 38, 47 and 56).

Results for beech woodland in either Scotland or England measure in hundreds of £millions. Broadleaf planting overall is expected to lock in £921 million worth of carbon in the next 200 years. By comparison, conifer planting is expected to add only £188-£333 million. Thus, the total carbon sequestration value of future planting, regardless of the likely prevalence of planting conifers on peat, varies relatively little, at £1.11-1.25 billion.

Conifer woodland has 20-36% the value of broadleaf forest, although conifers made up 26% of new planting in Table 21. Sitka spruce estimates tend to be reduced due to planting on upland and/or peaty soils. We know this because our models indicate that the carbon absorption potentials of each species are very similar at median YC values (12 for Sitka, 6 for beech), for similar soil types. For instance, a Sitka stand, YC=12 and a beech stand YC=6 planted in 2002, under a regime with discount rate = 3.5%, on lowland soils contain carbon with net present worth of, respectively, £2797 and £2414 per ha. The shorter rotation length and quicker release period for wood products almost reduces the C sequestration potential of the Sitka to that of beech at half the yield class. When Sitka is under-valued relative to its frequency of planting, this is due almost exclusively to a bias towards afforestation of uplands and peatlands.

7. Model Improvements

There are multiple small biases in the work, as described in Table 24. The final column gives some indication of the possible net effect of the given bias on our final valuation, on either a per hectare or regional basis. Generally, the suggested changes were worked out on a per hectare basis by varying relevant factors and extrapolating these to likely national scenarios. These postulated changes are not meant to be definitive assessments; we cannot calculate the true bias of each model component or assumption without making all calculations again, using the “true” value for each of the relevant unknown variable. Nor are the percentage changes cumulative; some refer to the same lack of information. For instance, if reliable planting year data were available for most subcompartments, then a separate map of “ancient” woodland would probably be redundant.

Reliable planting year and rotation data would add the most precision to our models. After that, the greatest improvement to our models would be higher resolution information about underlying soils, as well as post-afforestation carbon gains/losses in peat soils. In addition, stand-specific data on management regimes (especially thinning dates), historical land use, and actual felling dates might make the assessment much more reliable. Yield class assignments from actual field measurements would be preferable, but a median single YC value can probably be safely used on a regional basis (Section 6.1.2). Our models of sequestration rates into live wood could also be refined.

Table 24. Sequestration model and methodology biases

	Description, and alternative assumptions	Conceivable Magnitude change in NPV if assumption/methodology revised
Downward biases		
No renewal of C fixing between rotations on peat	Afforested peat has been observed (Hargreaves *et al.* 2001) to enter periods of renewed carbon absorption while the tree canopy is still open; research is lacking about whether this phenomenon occurs during only the first or in all rotations.	+125% to 220%, only on relevant soils.
Use of single "average" planting dates where PLYR unknown, and likewise, use of single values where ROTN unknown.	Likely to overlook ancient woodlands. Has a "group" effect on final carbon valuations.	+5 to 30%, especially for broadleaf forests. likely to be a small bias on a regional scale.
Use of FIAP indicated felling dates	Some stands are not managed with commercial criteria upmost.	<+20% for conifers +5 to 35% for broadleaves
Assumption of 10,000 ha in Xmas tree prod	May be too high. Longer-growing trees store more carbon.	< +5% for non-FC conifers
Upward biases		
Inclusion of previously felled woody products in current C stocks	Alternatively, carbon accrued during previous rotations could be omitted. Broadleaf estimates would be significantly reduced; conifer estimates would change relatively little.	Where rotation >1, -18 to -26%, Sitka YC=12 -28 to -29%, Beech YC=6
Loss of carbon sink=.25tC/ha on thick peat	Much higher typical per annum C uptake in undisturbed peatlands may occur (e.g., 0.4-0.7 tC/ha/yr, Cannell and Milne 1995).	See Section 6.1.1 for per ha, changes, but regionally, -2 to -30%, conifers <-5% broadleaves;
Assumption of tree spacing =1.7m when spacing unknown.	Likely to be too low. Higher spacing would mean lower yields, less carbon in live trees.	-16 to -30%, especially in private broadleaf forest

Upward biases (continued)		
Treatment of leaf litter	Simplistic; probably over-estimates C gains early in rotation.	< -2% for existing stands. < -3% for future woodlands.
Bias direction variable		
Loss of carbon sink=.0373tC/ha on thin peat	Carbon accumulation rates in these soils are uncertain.	+10 to -90%, conifers +5 to –10%, broadleaves; only on relevant soils; see Section 6.1.1.
Cumulative C emissions = -750 for thick peat	This figure may be too low or too high.	-10 to +20% on a regional basis; see Section 6.1.1.
Imprecise map data on ancient woodland	Stands designated as ‘ancient’ woodland may be misidentified; average age of current mature trees on these plots is unknown. Issue of whether to include benefits sunk so long ago becomes pertinent.	+/- £900 (YC=2) to +/- £6000 (YC=24) per ha, at individual sites, but <10% change on national totals.
Use of age-based variable when estimating YC (Models 1-2).	May reflect sampling bias rather than factors genuinely influencing growth rates	<+/-5% in broadleaf trees, mostly on private estate
Regression to predict live wood sequestration	Reduces sequestration estimates in high YC trees, and over-estimates C uptake in low YC trees.	+/-20% for very low or high YC, very small effect on regional totals.

The net GHG budget from woodlands, particularly rates of absorption/emission post-afforestation, needs to be much better understood. Consideration of methane and nitrous oxide releases/sinks would allow the production of a more complete picture of the impact of GB forestry on GHG emissions, rather than the carbon-only picture that we present here.

Probably only small improvements in the sequestration models would result from better estimates for knowing the exact amount of carbon gain or loss in soils. The rates of release/storage are very important, but the actual cumulative totals, and the length of the release period, are much less crucial. This is because of the impact of discounting, and is an important point. We would obviously prefer to utilise realistic figures for periods of carbon release/sequestration. There may be debate about the time periods we choose for losses/gains to continue to occur. We do not pretend that all of our assumptions are ideal, especially as research on GHG emissions is very much ongoing. However, to some, if not great extent, discounting renders irrelevant lengthy consideration of storage or release periods, and the exact amount of gain/release. Even at our lowest discount rate (2%), net carbon sequestered in 2103 (100 years after base year) is only worth 14% of the 2003 value. Discounting means that our final valuations are influenced most heavily by our calculations of current carbon storage in 2003, and the marginal net additions in the first few decades thereafter. Thus while the modelling of carbon sequestration itself would benefit from better estimates of release/storage periods and totals, refinements in this area are not likely to make a significant impact on final monetary valuations.

Finally, it might be interesting to alter the models such that they make direct allowance for social benefits and criteria. For instance, optimal felling ages could be modified as a direct result of carbon value; in effect, the value of carbon stored for longer in standing trees could be explicitly incorporated into the calculation of "optimal" felling date.

Acknowledgements

We received much appreciated feedback from Ken Willis (University of Newcastle Upon Tyne) and Ronnie Milne and Ken Hargreaves (both of CEH Edinburgh). Valuable advice on several aspects of soil data was received from Ian Bradley of the National Soil Resources Institute, Cranfield University. We appreciate the time taken by numerous individuals who read and commented on earlier drafts of this report, including (in no particular order): Pat Snowdon, Mark Broadmeadow, Simon Gillam, Robert Matthews, Peter Weston, Michael Thomson, (all Forestry Commission), James Vause (DEFRA), Hilary Miller (Countryside Council for Wales) and Colin MacBean (Scottish Executive).

References

Adger WN, Brown K, Sheil RS and Whitby MC (1992) "Carbon dynamics of land use in Great Britain, *Journal of Environmental Management* **36,** 117-133.

Arrow, K.J. Parikh, J. and Pillet, G., with contributions from Babu, P.G., Beltratti, A., Chichilnisky, G., Fankhauser, S., Faucheux, S., Froger, G., Gassmann, F., Haites, E.F., Hediger, W., Hourcade, J-Ch., Morgan, M.G., Parikh, H., Pearce, D.W., Peck, S., Richels, R., Schubert, R., Suarez, C. and Wellenmann, U. (1996) *Decision Making Framework to Address Climate Change*, report by IPCC Working Group III Writing Team II, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Askew GP, Payton RW and Sheil RS (1985) "Upland soils and land clearance in Britain during the second millennium BC", in Spratt D and Burgess C (eds) *Upland Settlement in Britain: The Second Millennium BC and After.* British Archaeological Report, British Series **143**, 5-33.

Bateman IJ and Lovett AA (1998) Using geographical information systems (GIS) and large area databases to predict yield class: a study of Sitka spruce in Wales, *Forestry* **71,** 147-168.

Bateman IJ and Lovett AA (2000). Estimating and valuing the carbon sequestered in softwood and hardwood trees, timber products and forest soils in Wales. *Journal of Environmental Management* **60**, 301-323.

Bateman IJ, Lovett AA and Brainard JS (2003) *Applied Environmental Economics: A GIS Approach to Cost-benefit Analysis,* Cambridge University Press, Cambridge.

Bousquet P, Peylin P, Ciais P, Le Quere C, Friedlingstein P and Tans PP (2000). Regional changes in carbon dioxide fluxes of land and oceans since 1980. *Science* **290**, 1342-1346.

Cannell MGR (1999). Growing trees to sequester carbon in the UK: answers to some common questions. *Forestry* 72(3) 237-247.

Cannell M and Cape J (1991) International environmental impacts: acid rain and the greenhouse effect, in: *Forestry Expansion: a Study of Technical, Economic and Ecological Factors: Paper No.2,* Forestry Commission, Alice Holt Lodge Research Station, Farnham, Surrey.

Cannell MGR, Cruickshank MM and Mobbs DC (1996). Carbon storage and sequestration in the forests of Northern Ireland. *Forestry* **69,** 155-165.

Cannell MGR, Dewar RC and Pyatt DG (1993) Conifer plantations on drained peatlands in Britain: a net gain or loss of carbon? *Forestry* **66**, 353-369

Cannell MGR and Dewar RC (1995) The carbon sink provided by plantation forests and their products in Britain. *Forestry* **68**, 35-48.

Cannell MGR and Milne R (1995) Carbon pools and sequestration in forest ecosystems in Britain *Forestry* **68**, 361-378.

CEH (Centre for Ecology and Hydrology) (2002) *Critical Appraisal of State and Pressures and Controls on the Sustainable Use of Soils in Wales*, CEH Project C01920, Environment Agency/ National Assembly for Wales Contract 11406.

Chapman SJ and Thurlow M (1998) Peat respiration at low temperatures. *Soil Biology and Biochemistry* **30**, 1013-1021.

Chapman SJ, Towers W, Williams BL, Coull MC and Paterson E (2001) *Review Of The Contribution to Climate Change of Organic Soils Under Different Land Uses,* Scottish Executive Central Research Unit, Edinburgh. Also at http://www.scotland.gov.uk/cru/kd01/lightgreen/rccs-00.asp.

Christiansen T and Torkington N (1998) *Perl Cookbook* O'Reilly and Associates, Inc. Sebastopol, CA, USA. Also see www.perl.com.

Clarkson R and Deyes K (2002) Estimating the Social Cost of Carbon Emissions, *Government Economic Service Working Paper 140*, Department of Environment, Food and Rural Affairs: London.

Corbyn IN, Crockford KJ and Savill PS (1988) The estimation of the branchwood component of broadleaved woodlands *Forestry* **61** (3): 193-204.

Crill P, Hargreaves K and Korhola A (2000) *The role of peat in Finnish greenhouse gas balances* Ministry of Trade and Industry, Helsinki.

DEFRA (Department for Environment, Food and Rural Affairs) (2002). *Digest of Environmental Statistics.* http://www.defra.gov.uk/environment/statistics/des/index.htm.

DeLucia E, Hamilton J, Naidu S, Thomas R, Andrews J, Finzi A, Lavine M, Matamala R, Mohan J, Hendrey G and W Schlesinger (1999) Net primary production of a forest ecosystem with experimental CO_2 enrichment. *Science* **284,**1177-1179.

Dewar RC and Cannell MGR (1992) Carbon sequestration in the trees, products and soils of forest plantations: An analysis using UK examples *Tree Physiology* **11,** 49-72.

Domencich T and McFadden DL (1975) *Urban Travel Demand: A Behavioral Analysis,* North-Holland Publishing Co., Amsterdam, The Netherlands. Also at:

http://emlab.berkeley.edu/users/mcfadden/travel.html

Edwards PN and Christie JM (1981) Yield models for forest management *Forestry Commission Booklet 48*, HMSO, London.

Elston DA, Jayasinghe G, Buckland ST, Macmillan DC and Aspinall RJ (1997) Adapting regression equations to minimise the mean squared error of predictions made using covariate data from a GIS *International Journal of Geographical Information Science* **11**, 265-280.

Eyre N, Downing TE, Hoekstra R and Tol R (1999). *Global Warming Damages, Final Report of the ExternE Global Warming Sub-Task (Sept.98)*, DGXII, European Commission, Brussels.

Fankauser S (1994). The social costs of greenhouse gas emissions: an expected value approach. *The Energy Journal* **15**, 157-184.

Fankauser S (1995). *Valuing Climate Change: The Economics of the Greenhouse* Earthscan, London.

FC (Forestry Commission) (1992) *Forestry Facts and Figures*, Forestry Commission, Edinburgh.

FC (Forestry Commission) (2001a) *Forestry Statistics*, Economics and Statistics Unit, Forestry Commission, Edinburgh.
7
FC (Forestry Commission) (2001b) *National Inventory of Woodland and trees -- England* Forest Research, Forestry Commission, Edinburgh. Also see http://www.forestry.gov.uk/forestry/hcou-54pg9u.

FC (Forestry Commission) (2001c) *National Inventory of Woodland and trees -- Scotland* Forest Research, Forestry Commission, Edinburgh. Also see http://www.forestry.gov.uk/forestry/hcou-54pg9t.

FC (Forestry Commission) (2002) *National Inventory of Woodland and trees -- Wales* Forest Research, Forestry Commission, Edinburgh. Also see http://www.forestry.gov.uk/forestry/hcou-54pg9v.

Gough C, Shackley, S and Cannell MGR (2002) *Evaluating the options for carbon sequestration* Tyndall Centre Technical Report 2, Tyndall Centre for Climate Change Research.

Haines-Young RH. Barr CJ, Black HIJ, Briggs DJ, Bunce RGH, Clarke RT, Cooper A, Dawson FH, Firbank LG, Fuller RM, Furse MT, Gillespie MK, Hill R, Hornung M, Howard DC, McCann T, Morecroft MD, Petit S, Sier ARJ, Smart SM, Smith GM,. Stott AP, Stuart RC and Watkins JW (2000). *Accounting for Nature: Assessing Habitats in the UK Countryside* DETR, London ISBN 1 85112 460 8. Also on http://www.cs2000.org.uk/.

Hamilton JG, DeLucia EH, George K, Naidu SL, Finzi AC and Schlesinger WH (2002) Forest carbon balance under elevated CO_2, *Oecologia* **131**:250–260

Hargreaves KJ, Milne R and Cannell MGR (2001). Carbon balance of afforested peatland in Scotland. in *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*, Report April 2001. Centre for Ecology & Hydrology, Edinburgh.

Hargreaves KJ, Milne R and Cannell MGR (2003) Carbon balance of afforested peatland in Scotland. *Forestry*. (In Press).

IPCC (Intergovernmental Panel on Climate Change) (1996) Climate Change1995 – Economic and Social Dimensions, *Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, Cambridge University Press.

Karjalainen T and Asikainen A (1996). Greenhouse gas emissions from the use of primary energy in forest operations and long-distance transportation of timber in Finland. *Forestry* **69**, 215-228.

Kasimir-Klemedtsson A, Klemedtsson L, Berglund K, Martikainen P, Silvola J and Oenema O (1997) Greenhouse gas emissions from farmed organic soils: A review, *Soil Use and Management* **13**, 245-250.

Leffelaar PA, Langeveld CA, Hofman JE, Segers R, Pol-Dasselaar van den A van. Goudriaan J, Rabbinge R and Oenema O (2000) Het geintegreerde lachgas en methaan grasland project ("The integrated nitrous oxide and methane grassland project") *NOP Rapport 410200038.* Available at NOP. Order by e-mail nopsecr@rivm.nl or at www.nop.nl

Macmillan DC (1991) Predicting the general yield class of Sitka spruce on better quality land in Scotland *Forestry* **64**, 359-372.

Marland G and Schlamadinger B (1997) Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. *Biomass and Bioenergy* **13**:389-397.

Marland G, Schlamadinger B and Leiby P (1997) Forest/biomass based mitigation strategies: does the timing of carbon reductions matter? *Critical Reviews in Environmental Science and Technology* **27**:S213-S226.

Matthews RW (1991) Biomass production and carbon storage by British forests, *mimeo*, Mensuration Branch, Forestry Commission, Alice Holt Lodge Research Station, Farnham, Surrey.

Matthews RW (1993) "Towards a methodology for the evaluation of the carbon budget of forests", *mimeo*, Mensuration Branch Forestry Commission, Alice Holt Lodge Research Station, Farnham, Surry..

Matthews R and Heaton R (2001) Effectiveness of carbon accounting methodologies for LULUCF and harvested wood products in supporting climate-conscious policy measures. In *UK Emissions by Sources and Removals by Sinks due to Land Use, Land*

Use Change and Forestry Activities, Report April 2001. Centre for Ecology & Hydrology, Edinburgh.

Matthews R and Methley J (1996) Site classification and yield prediction for lowland sites in England and Wales *Mensuration Branch Report, Supplement to Final Report,* Forestry Commission Research Division, Alice Holt Lodge, Farnham Surrey.

Matthews R, Methley J Alexander M, Jokiel P and Salisbury I (1996) Site classification and yield prediction for lowland sites in England and Wales *Mensuration Branch Report,* Forestry Commission Research Division, Alice Holt Lodge, Farnham Surrey.

McCullagh P (1980). Regression models for ordinal data. *Journal of the Royal Statistical Society B,* **42**,109-142.

Menard S (2001). *Applied Logistic Regression Analysis*. Sage University Papers Series on Quantitative Applications in the Social Sciences 07-106, Sage, Thousand Oaks, California.

Milne R and Brown TAW (2002). Mapping of carbon uptake in British woodlands and forests using EuroBiota and C-Flow. in *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*, Report, May 2002. Centre for Ecology & Hydrology, Edinburgh.

Milne R, Brown TAW and Murray TD (1998) The effect of geographical variation of planting rate on the uptake of carbon by new forests of Great Britain, *Forestry* **71**, 297-310.

Murray MB, Thornley J and Cannell MGR (2002) Modelling the impact of climate change and nitrogen deposition on carbon sequestration of UK plantation forests. in *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*, Report, May 2002- Centre for Ecology & Hydrology, Edinburgh.

Patenaude GL, Briggs BDJ, Milne R, Rowland CS, Dawson TP and Pryor SN (2003) The carbon pool in a British semi-natural woodland, *Forestry* **76**, 109-119.

Price C (1989) *Forest Economics.* Blackwell Publishers, Oxford, UK.

Price C (1993) *Time, Discounting and Value*, Blackwell Publishers, Oxford, UK.

Richey JE, Melack JM, Aufdenkampe AK, Ballester VM and Hess LL (2002) Outgassing from Amazonian rivers and wetlands as a large tropical source of atmospheric CO_2 *Nature* **416** (6881): 617-620.

Sampson RN (1992) “Forestry operations in the United Sates to mitigate the effects of global warming” *Water, Air and Soil Pollution* **64**: 157-180.

Taylor JA (1983). The Peatlands of Great Britain and Ireland. In Gore, AJP (ed.) *Ecosystems of the World Volume 4B, Mires: Swamp, Bog, Fen & Moor*. Elsevier Publishing Company, Amsterdam.

Thompson DA and Matthews RW (1989a) CO_2 in trees and timber lowers greenhouse effect, *Forestry and British Timber*, October: 19-22.

Thompson DA and Matthews RW (1989b) The storage of carbon in trees and timber, *Research Information Note 160*, Forestry Commission, Alice Holt Lodge Research Station, Farnham, Surrey.

Table 25. Estimate (£ millions) of social value of carbon in woodland in Eastern England. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.80	0.70	0.58
FC Oak	0.69	0.63	0.53
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	2.04	1.84	1.55
Other FC conifer	22.08	20.48	18.63
WI broadleaf	96.42	88.02	80.48
WI conifer	22.72	21.01	19.22
Thin Peat Soils			
FC Beech	0.01	0.01	0.00
FC Oak	0.02	0.02	0.01
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.07	0.06	0.05
Other FC conifer	0.32	0.31	0.28
WI broadleaf	1.97	1.71	1.36
WI conifer	0.41	0.39	0.35
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.04	0.04	0.03
WI broadleaf	0.92	0.81	0.53
WI conifer	0.04	0.04	0.03
Totals			
FC Beech	0.80	0.71	0.59
FC Oak	0.71	0.64	0.55
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	2.12	1.91	1.60
Other FC conifer	22.44	20.82	18.94
WI broadleaf	99.30	90.54	82.37
WI conifer	23.17	21.44	19.60
All FC woodland	26.07	24.09	21.67
All private woodland	122.47	111.98	101.97

Table 26. NPV estimate (£ millions) of social value of carbon in woodland in Eastern England. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	1.76	1.55	1.28
FC Oak	1.53	1.38	1.18
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	4.52	4.07	3.42
Other FC conifer	48.84	45.26	41.14
WI broadleaf	212.90	194.29	177.52
WI conifer	50.28	46.47	42.43
Thin Peat Soils			
FC Beech	0.01	0.01	0.01
FC Oak	0.05	0.04	0.03
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.15	0.14	0.10
Other FC conifer	0.71	0.69	0.61
WI broadleaf	4.34	3.77	3.00
WI conifer	0.89	0.86	0.76
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.01	0.01	0.01
Other FC conifer	0.08	0.08	0.07
WI broadleaf	2.02	1.77	1.18
WI conifer	0.10	0.09	0.07
Totals			
FC Beech	1.78	1.57	1.29
FC Oak	1.57	1.42	1.20
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	4.68	4.22	3.53
Other FC conifer	49.64	46.02	41.82
WI broadleaf	219.25	199.83	181.69
WI conifer	51.27	47.42	43.27
All FC woodland	57.67	53.23	47.85
All private woodland	270.52	247.25	224.96

Table 27. NPV estimate (£ millions) of social value of carbon in woodland in Eastern England. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	8.35	7.38	6.11
FC Oak	7.25	6.58	5.59
FC Sitka spruce	0.01	0.01	0.01
Other FC broadleaf	21.45	19.36	16.27
Other FC conifer	231.57	214.80	195.49
WI broadleaf	1011.85	923.91	844.93
WI conifer	238.23	220.40	201.67
Thin Peat Soils			
FC Beech	0.07	0.06	0.04
FC Oak	0.22	0.19	0.13
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.71	0.65	0.49
Other FC conifer	3.40	3.26	2.92
WI broadleaf	20.67	17.93	14.26
WI conifer	4.25	4.07	3.63
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.05	0.04	0.03
Other FC conifer	0.40	0.37	0.31
WI broadleaf	9.67	8.46	5.61
WI conifer	0.46	0.42	0.35
Totals			
FC Beech	8.42	7.44	6.15
FC Oak	7.47	6.77	5.72
FC Sitka spruce	0.01	0.01	0.01
Other FC broadleaf	22.21	20.05	16.79
Other FC conifer	235.36	218.43	198.71
WI broadleaf	1042.19	950.31	864.80
WI conifer	242.94	224.90	205.65
All FC woodland	273.48	252.70	227.38
All private woodland	1285.13	1175.21	1070.45

Table 28. NPV estimate (£ millions) of social value of carbon in woodland in East Midlands. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.46	0.43	0.36
FC Oak	1.73	1.60	1.38
FC Sitka spruce	0.07	0.06	0.06
Other FC broadleaf	3.28	2.97	2.48
Other FC conifer	6.11	5.72	5.25
WI broadleaf	66.51	61.50	56.90
WI conifer	11.19	10.37	9.50
Thin Peat Soils			
FC Beech	0.02	0.02	0.01
FC Oak	0.01	0.01	0.01
FC Sitka spruce	0.03	0.03	0.03
Other FC broadleaf	0.09	0.08	0.06
Other FC conifer	0.52	0.52	0.47
WI broadleaf	1.99	1.99	1.94
WI conifer	0.52	0.50	0.46
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.02	0.02	0.02
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	-0.01	-0.01	-0.01
WI broadleaf	0.06	0.05	0.03
WI conifer	0.00	0.00	0.00
Totals			
FC Beech	0.48	0.45	0.37
FC Oak	1.74	1.61	1.39
FC Sitka spruce	0.13	0.12	0.10
Other FC broadleaf	3.37	3.05	2.54
Other FC conifer	6.62	6.23	5.72
WI broadleaf	68.56	63.54	58.87
WI conifer	11.70	10.88	9.96
All FC woodland	12.34	11.47	10.13
All private woodland	80.26	74.42	68.83

Table 29. NPV estimate (£ millions) of social value of carbon in woodland in East Midlands. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	1.02	0.94	0.80
FC Oak	3.81	3.54	3.05
FC Sitka spruce	0.16	0.14	0.12
Other FC broadleaf	7.25	6.56	5.47
Other FC conifer	13.50	12.65	11.59
WI broadleaf	146.82	135.74	125.52
WI conifer	24.75	22.94	20.99
Thin Peat Soils			
FC Beech	0.04	0.04	0.03
FC Oak	0.02	0.02	0.02
FC Sitka spruce	0.08	0.07	0.06
Other FC broadleaf	0.20	0.18	0.13
Other FC conifer	1.14	1.14	1.05
WI broadleaf	4.39	4.38	4.27
WI conifer	1.14	1.11	1.01
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.05	0.05	0.04
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	-0.02	-0.01	-0.01
WI broadleaf	0.13	0.11	0.07
WI conifer	-0.01	0.00	0.00
Totals			
FC Beech	1.07	0.98	0.82
FC Oak	3.84	3.56	3.07
FC Sitka spruce	0.29	0.26	0.22
Other FC broadleaf	7.45	6.74	5.60
Other FC conifer	14.62	13.78	12.62
WI broadleaf	151.33	140.23	129.86
WI conifer	25.89	24.05	21.99
All FC woodland	27.26	25.33	22.35
All private woodland	177.22	164.28	151.85

Table 30. NPV estimate (£millions) of social value of carbon in woodland in East Midlands. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	4.87	4.49	3.79
FC Oak	18.11	16.83	14.54
FC Sitka spruce	0.74	0.68	0.58
Other FC broadleaf	34.42	31.21	26.04
Other FC conifer	64.05	60.04	55.08
WI broadleaf	698.03	645.58	597.42
WI conifer	117.30	108.83	99.74
Thin Peat Soils			
FC Beech	0.21	0.18	0.13
FC Oak	0.12	0.10	0.08
FC Sitka spruce	0.36	0.34	0.30
Other FC broadleaf	0.96	0.84	0.62
Other FC conifer	5.45	5.43	4.98
WI broadleaf	20.95	20.89	20.33
WI conifer	5.43	5.29	4.81
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.01	0.01	0.01
FC Sitka spruce	0.25	0.22	0.17
Other FC broadleaf	0.01	0.01	0.01
Other FC conifer	-0.10	-0.06	-0.06
WI broadleaf	0.62	0.54	0.35
WI conifer	-0.02	-0.02	-0.02
Totals			
FC Beech	5.08	4.68	3.92
FC Oak	18.24	16.95	14.63
FC Sitka spruce	1.35	1.24	1.05
Other FC broadleaf	35.39	32.06	26.67
Other FC conifer	69.40	65.41	60.00
WI broadleaf	719.60	667.00	618.10
WI conifer	122.70	114.10	104.53
All FC woodland	129.47	120.33	106.29
All private woodland	842.31	781.09	722.63

Table 31. NPV estimate (£millions) of social value of carbon in woodland in North East England. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.15	0.14	0.12
FC Oak	0.05	0.05	0.04
FC Sitka spruce	2.46	2.27	1.97
Other FC broadleaf	1.11	0.95	0.73
Other FC conifer	4.04	3.96	3.65
WI broadleaf	27.15	24.57	22.10
WI conifer	28.34	25.70	22.52
Thin Peat Soils			
FC Beech	0.01	0.01	0.01
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.87	0.81	0.70
Other FC broadleaf	0.50	0.42	0.30
Other FC conifer	1.93	1.97	1.83
WI broadleaf	1.03	0.91	0.76
WI conifer	5.08	4.78	4.16
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	1.32	1.21	1.05
Other FC broadleaf	0.03	0.02	0.02
Other FC conifer	0.01	0.05	0.06
WI broadleaf	0.01	0.01	0.01
WI conifer	1.71	1.63	1.40
Totals			
FC Beech	0.16	0.15	0.13
FC Oak	0.05	0.05	0.04
FC Sitka spruce	4.65	4.29	3.72
Other FC broadleaf	1.63	1.39	1.04
Other FC conifer	5.98	5.98	5.54
WI broadleaf	28.19	25.49	22.86
WI conifer	35.13	32.11	28.08
All FC woodland	12.48	11.86	10.48
All private woodland	63.32	57.59	50.94

Table 32. NPV estimate (£millions) of social value of carbon in woodland in North East England. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.33	0.30	0.26
FC Oak	0.11	0.10	0.09
FC Sitka spruce	5.44	5.01	4.36
Other FC broadleaf	2.46	2.11	1.61
Other FC conifer	8.91	8.74	8.06
WI broadleaf	59.90	54.24	48.75
WI conifer	62.73	56.85	49.77
Thin Peat Soils			
FC Beech	0.02	0.02	0.02
FC Oak	0.01	0.01	0.01
FC Sitka spruce	1.93	1.79	1.55
Other FC broadleaf	1.10	0.92	0.65
Other FC conifer	4.25	4.34	4.04
WI broadleaf	2.27	2.00	1.67
WI conifer	11.22	10.57	9.19
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	2.91	2.68	2.32
Other FC broadleaf	0.07	0.05	0.04
Other FC conifer	0.01	0.11	0.13
WI broadleaf	0.01	0.02	0.01
WI conifer	3.78	3.60	3.09
Totals			
FC Beech	0.35	0.32	0.28
FC Oak	0.12	0.11	0.10
FC Sitka spruce	10.28	9.48	8.23
Other FC broadleaf	3.62	3.08	2.30
Other FC conifer	13.17	13.18	12.23
WI broadleaf	62.18	56.25	50.43
WI conifer	77.74	71.01	62.05
All FC woodland	27.54	26.18	23.13
All private woodland	139.92	127.27	112.48

Table 33. NPV estimate (£millions) of social value of carbon in woodland in North East England. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	1.57	1.44	1.23
FC Oak	0.53	0.50	0.43
FC Sitka spruce	25.79	23.79	20.71
Other FC broadleaf	11.62	10.00	7.65
Other FC conifer	42.45	41.57	38.33
WI broadleaf	285.03	257.91	231.98
WI conifer	297.13	269.52	236.28
Thin Peat Soils			
FC Beech	0.11	0.10	0.08
FC Oak	0.04	0.03	0.03
FC Sitka spruce	9.16	8.48	7.36
Other FC broadleaf	5.20	4.37	3.11
Other FC conifer	20.30	20.66	19.22
WI broadleaf	10.80	9.51	7.93
WI conifer	53.27	50.14	43.63
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	13.82	12.71	11.00
Other FC broadleaf	0.31	0.25	0.17
Other FC conifer	0.08	0.54	0.62
WI broadleaf	0.07	0.07	0.05
WI conifer	17.99	17.08	14.68
Totals			
FC Beech	1.68	1.54	1.31
FC Oak	0.57	0.53	0.46
FC Sitka spruce	48.77	44.97	39.08
Other FC broadleaf	17.13	14.63	10.92
Other FC conifer	62.83	62.76	58.17
WI broadleaf	295.90	267.50	239.96
WI conifer	368.39	336.75	294.59
All FC woodland	130.98	124.43	109.94
All private woodland	664.29	604.25	534.56

Table 34. NPV estimate (£millions) of social value of carbon in woodland in North West England. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.21	0.19	0.15
FC Oak	0.18	0.17	0.15
FC Sitka spruce	30.79	28.47	24.81
Other FC broadleaf	1.34	1.19	0.96
Other FC conifer	3.03	2.88	2.63
WI broadleaf	59.72	54.03	49.08
WI conifer	26.79	24.27	21.43
Thin Peat Soils			
FC Beech	0.01	0.01	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	19.17	17.92	15.61
Other FC broadleaf	0.22	0.19	0.14
Other FC conifer	0.69	0.70	0.65
WI broadleaf	2.98	2.66	2.39
WI conifer	4.93	4.64	4.10
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	4.40	4.06	3.50
Other FC broadleaf	0.02	0.01	0.01
Other FC conifer	0.00	0.02	0.02
WI broadleaf	0.66	0.56	0.45
WI conifer	0.81	0.74	0.63
Totals			
FC Beech	0.21	0.19	0.16
FC Oak	0.18	0.17	0.15
FC Sitka spruce	54.36	50.45	43.91
Other FC broadleaf	1.57	1.40	1.11
Other FC conifer	3.73	3.60	3.30
WI broadleaf	63.36	57.26	51.92
WI conifer	32.53	29.66	26.16
All FC woodland	60.06	55.81	48.63
All private woodland	95.88	86.91	78.08

Table 35. NPV estimate (£millions) of social value of carbon in woodland in North West England. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.45	0.41	0.34
FC Oak	0.39	0.37	0.34
FC Sitka spruce	68.11	62.97	54.81
Other FC broadleaf	2.95	2.63	2.11
Other FC conifer	6.70	6.36	5.81
WI broadleaf	131.82	119.26	108.26
WI conifer	59.32	53.69	47.37
Thin Peat Soils			
FC Beech	0.01	0.01	0.01
FC Oak	0.01	0.01	0.00
FC Sitka spruce	42.40	39.63	34.50
Other FC broadleaf	0.49	0.43	0.31
Other FC conifer	1.52	1.54	1.43
WI broadleaf	6.56	5.87	5.28
WI conifer	10.89	10.26	9.05
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	9.74	8.98	7.72
Other FC broadleaf	0.04	0.03	0.02
Other FC conifer	0.00	0.04	0.04
WI broadleaf	1.46	1.24	0.99
WI conifer	1.79	1.65	1.39
Totals			
FC Beech	0.47	0.42	0.35
FC Oak	0.40	0.37	0.34
FC Sitka spruce	120.25	111.58	97.04
Other FC broadleaf	3.48	3.09	2.44
Other FC conifer	8.23	7.95	7.28
WI broadleaf	139.85	126.37	114.52
WI conifer	72.01	65.60	57.81
All FC woodland	132.83	123.41	107.44
All private woodland	211.85	191.97	172.34

Table 36. NPV estimate (£millions) of social value of carbon in woodland in North West England. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	2.15	1.95	1.61
FC Oak	1.86	1.75	1.60
FC Sitka spruce	322.89	298.60	260.28
Other FC broadleaf	14.02	12.51	10.04
Other FC conifer	31.84	30.23	27.64
WI broadleaf	626.76	567.12	515.27
WI conifer	280.83	254.54	224.85
Thin Peat Soils			
FC Beech	0.06	0.05	0.04
FC Oak	0.03	0.03	0.02
FC Sitka spruce	201.08	187.95	163.81
Other FC broadleaf	2.31	2.03	1.48
Other FC conifer	7.28	7.34	6.78
WI broadleaf	31.29	27.95	25.15
WI conifer	51.73	48.71	43.00
Thick Peat Soils			
FC Beech	0.01	0.01	0.01
FC Oak	0.00	0.00	0.00
FC Sitka spruce	46.20	42.58	36.68
Other FC broadleaf	0.17	0.13	0.09
Other FC conifer	0.03	0.19	0.19
WI broadleaf	6.95	5.92	4.72
WI conifer	8.49	7.80	6.61
Totals			
FC Beech	2.23	2.02	1.66
FC Oak	1.89	1.78	1.62
FC Sitka spruce	570.16	529.13	460.76
Other FC broadleaf	16.51	14.67	11.60
Other FC conifer	39.16	37.76	34.61
WI broadleaf	665.00	600.99	545.14
WI conifer	341.05	311.05	274.46
All FC woodland	629.94	585.36	510.26
All private woodland	1006.04	912.04	819.60

Table 37. NPV estimate (£millions) of social value of carbon in woodland in Scotland. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.46	0.42	0.35
FC Oak	0.77	0.72	0.65
FC Sitka spruce	200.45	179.27	153.69
Other FC broadleaf	14.04	12.46	10.05
Other FC conifer	52.14	51.49	48.06
WI broadleaf	198.92	172.06	147.82
WI conifer	415.69	352.48	289.24
Thin Peat Soils			
FC Beech	0.09	0.08	0.06
FC Oak	-0.03	-0.04	-0.06
FC Sitka spruce	109.32	98.75	84.33
Other FC broadleaf	4.37	3.88	2.89
Other FC conifer	25.52	26.37	24.86
WI broadleaf	54.16	44.18	34.41
WI conifer	225.30	190.98	154.33
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	-0.01	-0.01	-0.01
FC Sitka spruce	19.39	16.94	14.04
Other FC broadleaf	0.31	0.24	0.15
Other FC conifer	2.02	2.27	2.15
WI broadleaf	6.39	4.03	2.21
WI conifer	30.32	25.33	19.90
Totals			
FC Beech	0.55	0.50	0.42
FC Oak	0.74	0.67	0.58
FC Sitka spruce	329.15	294.97	252.06
Other FC broadleaf	18.72	16.58	13.09
Other FC conifer	79.68	80.13	75.08
WI broadleaf	259.47	220.26	184.43
WI conifer	671.31	568.80	463.47
All FC woodland	428.84	392.85	341.22
All private woodland	930.78	789.06	647.90

Table 38. NPV estimate (£millions) of social value of carbon in woodland in Scotland. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	1.02	0.93	0.78
FC Oak	1.71	1.58	1.43
FC Sitka spruce	443.99	396.79	339.72
Other FC broadleaf	31.05	27.53	22.16
Other FC conifer	114.91	113.61	106.07
WI broadleaf	439.79	380.34	326.33
WI conifer	924.21	782.16	640.56
Thin Peat Soils			
FC Beech	0.20	0.18	0.14
FC Oak	-0.06	-0.09	-0.13
FC Sitka spruce	242.01	218.53	186.40
Other FC broadleaf	9.65	8.57	6.37
Other FC conifer	56.07	58.13	54.84
WI broadleaf	119.88	97.80	76.01
WI conifer	500.99	423.93	341.91
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	-0.02	-0.02	-0.02
FC Sitka spruce	42.98	37.54	31.04
Other FC broadleaf	0.70	0.54	0.34
Other FC conifer	4.41	4.99	4.75
WI broadleaf	14.36	9.03	4.93
WI conifer	67.47	56.29	44.12
Totals			
FC Beech	1.22	1.11	0.92
FC Oak	1.63	1.48	1.28
FC Sitka spruce	728.99	652.85	557.16
Other FC broadleaf	41.41	36.64	28.87
Other FC conifer	175.39	176.74	165.66
WI broadleaf	574.03	487.17	407.27
WI conifer	1,492.67	1,262.38	1,026.60
All FC woodland	948.64	868.82	753.90
All private woodland	2,066.70	1,749.56	1,433.87

Table 39. NPV estimate (£millions) of social value of carbon in woodland in Scotland 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	4.86	4.40	3.71
FC Oak	8.14	7.53	6.79
FC Sitka spruce	2101.29	1879.86	1612.35
Other FC broadleaf	147.26	130.76	105.46
Other FC conifer	547.60	540.45	504.53
WI broadleaf	2086.71	1804.94	1551.40
WI conifer	4352.01	3692.56	3032.47
Thin Peat Soils			
FC Beech	0.95	0.85	0.68
FC Oak	-0.28	-0.41	-0.60
FC Sitka spruce	1146.19	1035.54	884.69
Other FC broadleaf	45.82	40.74	30.34
Other FC conifer	268.24	276.91	261.02
WI broadleaf	567.89	463.23	361.00
WI conifer	2358.66	2000.43	1617.78
Thick Peat Soils			
FC Beech	0.01	0.01	0.01
FC Oak	-0.09	-0.08	-0.08
FC Sitka spruce	203.18	177.62	147.21
Other FC broadleaf	3.29	2.52	1.61
Other FC conifer	21.26	23.86	22.63
WI broadleaf	66.62	42.06	23.08
WI conifer	317.24	265.27	208.60
Totals			
FC Beech	5.82	5.26	4.39
FC Oak	7.76	7.04	6.11
FC Sitka spruce	3,450.66	3,093.02	2,644.25
Other FC broadleaf	196.38	174.02	137.41
Other FC conifer	837.09	841.23	788.17
WI broadleaf	2,721.21	2,310.23	1,935.49
WI conifer	7,027.91	5,958.26	4,858.85
All FC woodland	4,497.72	4,120.57	3,580.33
All private woodland	9,749.13	8,268.49	6,794.34

Table 40. NPV estimate (£millions) of social value of carbon in woodland in South East England. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	8.34	7.63	6.49
FC Oak	6.26	5.95	5.58
FC Sitka spruce	0.11	0.10	0.09
Other FC broadleaf	8.01	7.37	6.26
Other FC conifer	15.71	14.55	13.27
WI broadleaf	269.81	246.52	227.11
WI conifer	38.52	35.69	32.61
Thin Peat Soils			
FC Beech	0.01	0.01	0.01
FC Oak	0.01	0.01	0.01
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.03	0.03	0.02
Other FC conifer	0.29	0.27	0.24
WI broadleaf	10.07	9.00	7.77
WI conifer	3.37	3.24	2.88
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	0.20	0.18	0.16
WI conifer	0.00	0.00	0.00
Totals			
FC Beech	8.36	7.64	6.50
FC Oak	6.27	5.96	5.58
FC Sitka spruce	0.11	0.10	0.09
Other FC broadleaf	8.05	7.40	6.28
Other FC conifer	15.99	14.82	13.51
WI broadleaf	280.08	255.70	235.03
WI conifer	41.90	38.93	35.50
All FC woodland	38.78	35.92	31.97
All private woodland	321.97	294.64	270.53

Table 41. NPV estimate (£millions) of social value of carbon in woodland in South East England. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	18.43	16.82	14.31
FC Oak	13.83	13.14	12.29
FC Sitka spruce	0.23	0.22	0.21
Other FC broadleaf	17.70	16.26	13.81
Other FC conifer	34.74	32.16	29.31
WI broadleaf	595.84	544.09	500.87
WI conifer	85.27	78.90	72.02
Thin Peat Soils			
FC Beech	0.03	0.03	0.02
FC Oak	0.02	0.02	0.01
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.07	0.06	0.05
Other FC conifer	0.63	0.60	0.54
WI broadleaf	22.17	19.84	17.13
WI conifer	7.44	7.16	6.37
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	0.44	0.40	0.35
WI conifer	0.01	0.01	0.01
Totals			
FC Beech	18.46	16.85	14.33
FC Oak	13.85	13.15	12.31
FC Sitka spruce	0.23	0.22	0.21
Other FC broadleaf	17.76	16.33	13.86
Other FC conifer	35.37	32.76	29.84
WI broadleaf	618.45	564.32	518.35
WI conifer	92.71	86.06	78.40
All FC woodland	85.68	79.32	70.55
All private woodland	711.16	650.38	596.75

Table 42. NPV estimate (£millions) of social value of carbon in woodland in South East England. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	87.57	80.05	68.15
FC Oak	65.72	62.50	58.54
FC Sitka spruce	1.11	1.06	0.99
Other FC broadleaf	84.12	77.37	65.74
Other FC conifer	164.75	152.66	139.27
WI broadleaf	2831.42	2587.65	2384.47
WI conifer	403.95	374.37	342.19
Thin Peat Soils			
FC Beech	0.16	0.14	0.10
FC Oak	0.09	0.09	0.06
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.32	0.31	0.22
Other FC conifer	3.00	2.85	2.55
WI broadleaf	105.76	94.47	81.58
WI conifer	35.37	34.00	30.28
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	2.11	1.91	1.66
WI conifer	0.05	0.05	0.04
Totals			
FC Beech	87.73	80.18	68.25
FC Oak	65.81	62.59	58.61
FC Sitka spruce	1.11	1.06	0.99
Other FC broadleaf	84.44	77.67	65.96
Other FC conifer	167.75	155.51	141.81
WI broadleaf	2,939.29	2,684.03	2,467.71
WI conifer	439.38	408.42	372.51
All FC woodland	406.84	377.02	335.62
All private woodland	3,378.67	3,092.45	2,840.22

Table 43. NPV estimate (£millions) of social value of carbon in woodland in South West England. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	3.42	3.13	2.59
FC Oak	2.95	2.77	2.50
FC Sitka spruce	5.95	5.40	4.69
Other FC broadleaf	5.05	4.55	3.77
Other FC conifer	14.51	13.38	12.11
WI broadleaf	193.12	174.64	159.07
WI conifer	48.65	44.74	40.67
Thin Peat Soils			
FC Beech	0.06	0.06	0.05
FC Oak	0.01	0.01	0.01
FC Sitka spruce	1.47	1.35	1.15
Other FC broadleaf	0.13	0.12	0.10
Other FC conifer	0.67	0.63	0.56
WI broadleaf	4.44	3.94	3.37
WI conifer	2.29	2.16	1.91
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.07	0.06	0.05
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	0.10	0.08	0.06
WI conifer	0.01	0.01	0.01
Totals			
FC Beech	3.48	3.18	2.64
FC Oak	2.96	2.78	2.51
FC Sitka spruce	7.49	6.81	5.89
Other FC broadleaf	5.18	4.67	3.87
Other FC conifer	15.18	14.02	12.67
WI broadleaf	197.65	178.67	162.50
WI conifer	50.95	46.91	42.58
All FC woodland	34.29	31.46	27.58
All private woodland	248.60	225.57	205.08

Table 44. NPV estimate (£millions) of social value of carbon in woodland in South West England. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	7.54	6.89	5.72
FC Oak	6.51	6.12	5.51
FC Sitka spruce	13.16	11.94	10.37
Other FC broadleaf	11.15	10.05	8.32
Other FC conifer	32.10	29.59	26.74
WI broadleaf	426.52	385.48	350.86
WI conifer	107.69	98.91	89.83
Thin Peat Soils			
FC Beech	0.14	0.13	0.11
FC Oak	0.02	0.02	0.01
FC Sitka spruce	3.26	2.98	2.54
Other FC broadleaf	0.30	0.27	0.22
Other FC conifer	1.47	1.40	1.25
WI broadleaf	9.77	8.70	7.43
WI conifer	5.06	4.78	4.22
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.15	0.13	0.10
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	0.21	0.18	0.13
WI conifer	0.01	0.01	0.01
Totals			
FC Beech	7.67	7.02	5.82
FC Oak	6.52	6.14	5.53
FC Sitka spruce	16.57	15.05	13.01
Other FC broadleaf	11.45	10.31	8.54
Other FC conifer	33.57	30.99	27.99
WI broadleaf	436.50	394.36	358.42
WI conifer	112.76	103.70	94.06
All FC woodland	75.79	69.52	60.89
All private woodland	549.26	498.06	452.47

Table 45. NPV estimate (£millions) of social value of carbon in woodland in South West England. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	35.85	32.81	27.22
FC Oak	30.97	29.13	26.25
FC Sitka spruce	62.38	56.66	49.24
Other FC broadleaf	52.97	47.76	39.62
Other FC conifer	152.20	140.41	127.07
WI broadleaf	2026.60	1833.04	1670.09
WI conifer	510.15	469.29	426.79
Thin Peat Soils			
FC Beech	0.66	0.62	0.52
FC Oak	0.08	0.08	0.06
FC Sitka spruce	15.47	14.12	12.05
Other FC broadleaf	1.42	1.27	1.03
Other FC conifer	6.99	6.66	5.93
WI broadleaf	46.58	41.41	35.37
WI conifer	24.01	22.67	20.03
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.70	0.60	0.48
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.01	0.01	0.01
WI broadleaf	1.02	0.87	0.61
WI conifer	0.07	0.07	0.06
Totals			
FC Beech	36.51	33.44	27.74
FC Oak	31.04	29.20	26.31
FC Sitka spruce	78.54	71.38	61.77
Other FC broadleaf	54.39	49.04	40.65
Other FC conifer	159.20	147.09	133.00
WI broadleaf	2,074.20	1,875.33	1,706.07
WI conifer	534.23	492.03	446.88
All FC woodland	359.69	330.15	289.48
All private woodland	2,608.43	2,367.36	2,152.94

Table 46. NPV estimate (£millions) of social value of carbon in woodland in Wales. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	1.94	1.76	1.48
FC Oak	1.69	1.55	1.34
FC Sitka spruce	52.20	47.13	40.70
Other FC broadleaf	6.25	5.56	4.56
Other FC conifer	28.85	26.78	24.26
WI broadleaf	115.46	103.92	92.91
WI conifer	44.73	40.72	36.06
Thin Peat Soils			
FC Beech	0.04	0.03	0.02
FC Oak	0.03	0.02	0.01
FC Sitka spruce	21.33	19.49	16.73
Other FC broadleaf	0.25	0.19	0.09
Other FC conifer	3.40	3.39	3.12
WI broadleaf	2.93	2.55	2.03
WI conifer	7.34	7.16	6.44
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	2.13	1.95	1.67
Other FC broadleaf	0.02	0.02	0.01
Other FC conifer	0.10	0.11	0.10
WI broadleaf	0.29	0.25	0.19
WI conifer	-0.12	-0.02	0.00
Totals			
FC Beech	1.98	1.79	1.50
FC Oak	1.72	1.57	1.35
FC Sitka spruce	75.66	68.56	59.09
Other FC broadleaf	6.52	5.76	4.66
Other FC conifer	32.36	30.28	27.48
WI broadleaf	118.67	106.73	95.13
WI conifer	51.95	47.86	42.50
All FC woodland	118.25	107.96	94.08
All private woodland	170.63	154.59	137.63

Table 47. NPV estimate (£millions) of social value of carbon in woodland in Wales. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	4.29	3.88	3.26
FC Oak	3.73	3.41	2.96
FC Sitka spruce	115.56	104.26	89.93
Other FC broadleaf	13.82	12.27	10.05
Other FC conifer	63.80	59.18	53.58
WI broadleaf	254.76	229.38	204.97
WI conifer	99.08	90.09	79.70
Thin Peat Soils			
FC Beech	0.08	0.07	0.05
FC Oak	0.07	0.05	0.02
FC Sitka spruce	47.21	43.11	36.97
Other FC broadleaf	0.55	0.41	0.20
Other FC conifer	7.49	7.49	6.88
WI broadleaf	6.46	5.63	4.49
WI conifer	16.20	15.81	14.22
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	4.72	4.31	3.68
Other FC broadleaf	0.04	0.04	0.03
Other FC conifer	0.23	0.25	0.23
WI broadleaf	0.63	0.56	0.41
WI conifer	-0.27	-0.06	0.00
Totals			
FC Beech	4.37	3.94	3.31
FC Oak	3.80	3.46	2.98
FC Sitka spruce	167.48	151.68	130.58
Other FC broadleaf	14.42	12.72	10.28
Other FC conifer	71.52	66.92	60.69
WI broadleaf	261.85	235.58	209.87
WI conifer	115.01	105.84	93.92
All FC woodland	261.59	238.72	207.84
All private woodland	376.86	341.41	303.79

Table 48. NPV estimate (£millions) of social value of carbon in woodland in Wales. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	20.39	18.44	15.51
FC Oak	17.72	16.24	14.10
FC Sitka spruce	547.32	494.25	426.97
Other FC broadleaf	65.62	58.30	47.82
Other FC conifer	302.66	280.90	254.60
WI broadleaf	1212.04	1090.82	975.37
WI conifer	468.97	427.11	378.40
Thin Peat Soils			
FC Beech	0.37	0.32	0.24
FC Oak	0.32	0.23	0.09
FC Sitka spruce	223.69	204.37	175.47
Other FC broadleaf	2.61	1.94	0.95
Other FC conifer	35.75	35.63	32.73
WI broadleaf	30.75	26.78	21.35
WI conifer	76.98	75.09	67.56
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	22.38	20.44	17.48
Other FC broadleaf	0.20	0.18	0.13
Other FC conifer	1.10	1.18	1.09
WI broadleaf	2.99	2.67	1.97
WI conifer	-1.21	-0.24	-0.01
Totals			
FC Beech	20.76	18.76	15.75
FC Oak	18.05	16.47	14.20
FC Sitka spruce	793.40	719.05	619.92
Other FC broadleaf	68.43	60.43	48.91
Other FC conifer	339.51	317.72	288.42
WI broadleaf	1,245.78	1,120.27	998.68
WI conifer	544.74	501.95	445.95
All FC woodland	1,240.14	1,132.43	987.20
All private woodland	1,790.52	1,622.22	1,444.63

Table 49. NPV estimate (£millions) of social value of carbon in woodland in West Midlands. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.51	0.47	0.39
FC Oak	0.80	0.75	0.68
FC Sitka spruce	0.45	0.41	0.36
Other FC broadleaf	1.80	1.63	1.34
Other FC conifer	6.02	5.59	5.06
WI broadleaf	82.83	76.56	71.27
WI conifer	22.20	20.81	19.32
Thin Peat Soils			
FC Beech	0.01	0.01	0.01
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.01	0.00	0.00
Other FC broadleaf	0.09	0.08	0.06
Other FC conifer	0.77	0.77	0.70
WI broadleaf	1.31	1.19	1.05
WI conifer	0.73	0.70	0.62
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	0.08	0.07	0.06
WI conifer	0.01	0.01	0.01
Totals			
FC Beech	0.52	0.48	0.40
FC Oak	0.79	0.75	0.68
FC Sitka spruce	0.46	0.42	0.36
Other FC broadleaf	1.89	1.71	1.40
Other FC conifer	6.79	6.35	5.76
WI broadleaf	84.21	77.82	72.38
WI conifer	22.93	21.53	19.95
All FC woodland	10.46	9.71	8.61
All private woodland	107.15	99.35	92.33

Table 50. NPV estimate (£millions) of social value of carbon in woodland in West Midlands. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	1.12	1.04	0.86
FC Oak	1.76	1.66	1.50
FC Sitka spruce	1.00	0.91	0.80
Other FC broadleaf	3.98	3.60	2.96
Other FC conifer	13.32	12.35	11.18
WI broadleaf	182.86	168.95	157.19
WI conifer	49.10	45.99	42.65
Thin Peat Soils			
FC Beech	0.03	0.02	0.02
FC Oak	0.00	0.00	-0.01
FC Sitka spruce	0.01	0.01	0.01
Other FC broadleaf	0.19	0.18	0.13
Other FC conifer	1.70	1.69	1.55
WI broadleaf	2.89	2.63	2.31
WI conifer	1.60	1.55	1.38
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	0.17	0.16	0.13
WI conifer	0.02	0.02	0.02
Totals			
FC Beech	1.15	1.06	0.88
FC Oak	1.75	1.66	1.49
FC Sitka spruce	1.02	0.92	0.81
Other FC broadleaf	4.17	3.77	3.10
Other FC conifer	15.02	14.03	12.73
WI broadleaf	185.91	171.73	159.63
WI conifer	50.73	47.56	44.04
All FC woodland	23.11	21.45	19.01
All private woodland	236.64	219.29	203.67

Table 51. NPV estimate (£millions) of social value of carbon in woodland in West Midlands. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	5.35	4.94	4.11
FC Oak	8.36	7.91	7.14
FC Sitka spruce	4.75	4.31	3.78
Other FC broadleaf	18.90	17.10	14.11
Other FC conifer	63.17	58.59	53.11
WI broadleaf	869.29	803.66	748.32
WI conifer	232.83	218.38	202.72
Thin Peat Soils			
FC Beech	0.14	0.12	0.09
FC Oak	-0.02	-0.02	-0.03
FC Sitka spruce	0.05	0.05	0.04
Other FC broadleaf	0.93	0.84	0.64
Other FC conifer	8.09	8.03	7.36
WI broadleaf	13.78	12.52	10.99
WI conifer	7.63	7.36	6.54
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.00	0.00	0.00
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.00	0.00
WI broadleaf	0.81	0.75	0.64
WI conifer	0.09	0.11	0.09
Totals			
FC Beech	5.49	5.05	4.20
FC Oak	8.33	7.89	7.12
FC Sitka spruce	4.81	4.36	3.82
Other FC broadleaf	19.83	17.94	14.75
Other FC conifer	71.26	66.63	60.47
WI broadleaf	883.87	816.92	759.95
WI conifer	240.55	225.85	209.35
All FC woodland	109.72	101.88	90.36
All private woodland	1124.42	1042.77	969.30

Table 52. NPV estimate (£millions) of social value of carbon in woodland in Yorks & Humber. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.21	0.19	0.15
FC Oak	0.25	0.23	0.20
FC Sitka spruce	3.25	2.96	2.57
Other FC broadleaf	1.72	1.54	1.26
Other FC conifer	5.30	5.03	4.62
WI broadleaf	63.33	58.02	53.37
WI conifer	23.87	21.74	19.31
Thin Peat Soils			
FC Beech	0.03	0.02	0.02
FC Oak	0.02	0.02	0.02
FC Sitka spruce	1.85	1.71	1.47
Other FC broadleaf	0.20	0.18	0.13
Other FC conifer	1.48	1.50	1.40
WI broadleaf	3.22	2.98	2.72
WI conifer	3.90	3.69	3.22
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.04	0.03	0.03
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.00	0.01	0.01
WI broadleaf	0.45	0.41	0.33
WI conifer	0.64	0.62	0.54
Totals			
FC Beech	0.24	0.21	0.17
FC Oak	0.27	0.25	0.22
FC Sitka spruce	5.13	4.70	4.07
Other FC broadleaf	1.92	1.71	1.39
Other FC conifer	6.79	6.54	6.02
WI broadleaf	67.00	61.41	56.42
WI conifer	28.42	26.04	23.08
All FC woodland	14.35	13.41	11.88
All private woodland	95.42	87.46	79.50

Table 53. NPV estimate (£millions) of social value of carbon in woodland in Yorks & Humber. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	0.47	0.41	0.33
FC Oak	0.56	0.52	0.45
FC Sitka spruce	7.19	6.55	5.69
Other FC broadleaf	3.81	3.39	2.78
Other FC conifer	11.72	11.11	10.20
WI broadleaf	139.78	128.04	117.70
WI conifer	52.86	48.08	42.68
Thin Peat Soils			
FC Beech	0.06	0.05	0.04
FC Oak	0.05	0.04	0.03
FC Sitka spruce	4.09	3.77	3.25
Other FC broadleaf	0.43	0.39	0.30
Other FC conifer	3.25	3.31	3.08
WI broadleaf	7.09	6.57	6.00
WI conifer	8.63	8.16	7.12
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.08	0.07	0.06
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.01	0.01	0.01
WI broadleaf	0.98	0.90	0.73
WI conifer	1.41	1.36	1.19
Totals			
FC Beech	0.53	0.46	0.37
FC Oak	0.61	0.56	0.49
FC Sitka spruce	11.36	10.40	9.00
Other FC broadleaf	4.24	3.78	3.07
Other FC conifer	14.98	14.43	13.30
WI broadleaf	147.85	135.51	124.43
WI conifer	62.90	57.60	50.98
All FC woodland	31.72	29.63	26.23
All private woodland	210.75	193.12	175.41

Table 54. NPV estimate (£millions) of social value of carbon in woodland in Yorks & Humber. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	2.22	1.95	1.58
FC Oak	2.67	2.45	2.15
FC Sitka spruce	34.06	31.07	27.01
Other FC broadleaf	18.07	16.11	13.22
Other FC conifer	55.66	52.79	48.49
WI broadleaf	664.80	609.07	560.32
WI conifer	250.31	227.96	202.65
Thin Peat Soils			
FC Beech	0.28	0.25	0.18
FC Oak	0.22	0.21	0.16
FC Sitka spruce	19.41	17.89	15.45
Other FC broadleaf	2.06	1.87	1.41
Other FC conifer	15.52	15.74	14.68
WI broadleaf	33.84	31.32	28.58
WI conifer	40.98	38.73	33.80
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	0.00	0.00	0.00
FC Sitka spruce	0.38	0.33	0.27
Other FC broadleaf	0.00	0.00	0.00
Other FC conifer	0.05	0.06	0.05
WI broadleaf	4.69	4.27	3.47
WI conifer	6.72	6.48	5.66
Totals			
FC Beech	2.50	2.20	1.76
FC Oak	2.88	2.66	2.31
FC Sitka spruce	53.84	49.29	42.73
Other FC broadleaf	20.14	17.98	14.63
Other FC conifer	71.24	68.59	63.22
WI broadleaf	703.34	644.66	592.37
WI conifer	298.00	273.17	242.11
All FC woodland	150.60	140.71	124.65
All private woodland	1001.35	917.82	834.48

Table 55. NPV estimate (£millions) of social value of carbon in woodland in Great Britain. 2003 value of carbon = £6.67, with annual increments of 6.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	16.50	15.04	12.67
FC Oak	15.37	14.42	13.06
FC Sitka spruce	295.72	266.08	228.94
Other FC broadleaf	44.65	40.07	32.96
Other FC conifer	157.80	149.85	137.55
WI broadleaf	1,173.26	1,059.85	960.11
WI conifer	682.70	597.54	509.89
Thin Peat Soils			
FC Beech	0.29	0.26	0.20
FC Oak	0.08	0.05	0.00
FC Sitka spruce	154.06	140.05	120.02
Other FC broadleaf	5.94	5.23	3.84
Other FC conifer	35.58	36.43	34.12
WI broadleaf	84.09	71.11	57.79
WI conifer	253.86	218.25	178.46
Thick Peat Soils			
FC Beech	0.00	0.00	0.00
FC Oak	-0.01	-0.01	-0.01
FC Sitka spruce	27.37	24.27	20.33
Other FC broadleaf	0.39	0.30	0.19
Other FC conifer	2.17	2.49	2.37
WI broadleaf	9.14	6.45	4.03
WI conifer	33.42	28.36	22.52
Totals			
FC Beech	16.79	15.30	12.87
FC Oak	15.44	14.47	13.06
FC Sitka spruce	477.15	430.41	369.30
Other FC broadleaf	50.98	45.59	36.99
Other FC conifer	195.56	188.77	174.03
WI broadleaf	1,266.49	1,137.42	1,021.92
WI conifer	969.98	844.14	710.87
All FC woodland	755.91	694.54	606.24
All private woodland	2,236.48	1,981.56	1,732.79

Table 56. NPV estimate (£millions) of social value of carbon in woodland in Great Britain. 2003 value of carbon = £14.70, with annual increments of 16.67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	36.44	33.18	27.93
FC Oak	33.93	31.82	28.80
FC Sitka spruce	654.84	588.80	506.01
Other FC broadleaf	98.69	88.47	72.70
Other FC conifer	348.56	331.01	303.70
WI broadleaf	2,590.97	2,339.79	2,117.96
WI conifer	1,515.30	1,324.08	1,127.99
Thin Peat Soils			
FC Beech	0.63	0.56	0.44
FC Oak	0.17	0.11	0.00
FC Sitka spruce	341.00	309.90	265.28
Other FC broadleaf	13.14	11.55	8.46
Other FC conifer	78.24	80.33	75.27
WI broadleaf	185.82	157.19	127.56
WI conifer	564.06	484.18	395.23
Thick Peat Soils			
FC Beech	0.01	0.00	0.00
FC Oak	-0.02	-0.01	-0.02
FC Sitka spruce	60.64	53.74	44.96
Other FC broadleaf	0.86	0.67	0.43
Other FC conifer	4.73	5.47	5.21
WI broadleaf	20.41	14.38	8.94
WI conifer	74.33	62.97	49.91
Totals			
FC Beech	37.08	33.75	28.38
FC Oak	34.08	31.92	28.79
FC Sitka spruce	1,056.47	952.45	816.24
Other FC broadleaf	112.68	100.69	81.59
Other FC conifer	431.52	416.81	384.18
WI broadleaf	2,797.21	2,511.36	2,254.46
WI conifer	2,153.68	1,871.23	1,573.13
All FC woodland	1,671.83	1,535.61	1,339.17
All private woodland	4,950.89	4,382.59	3,827.59

Table 57. NPV estimate (£millions) of social value of carbon in woodland in Great Britain. 2003 value of carbon = £70, with annual increments of 67 pence to year 2031.

	Discount rates		
	2%	3.5%	6%
Mineral Soils			
FC Beech	173.19	157.86	133.01
FC Oak	161.32	151.42	137.14
FC Sitka spruce	3,100.34	2,790.29	2,401.92
Other FC broadleaf	468.46	420.49	345.97
Other FC conifer	1,655.95	1,572.45	1,443.59
WI broadleaf	12,312.53	11,123.69	10,079.57
WI conifer	7,151.71	6,262.96	5,347.75
Thin Peat Soils			
FC Beech	3.00	2.69	2.10
FC Oak	0.81	0.52	0.01
FC Sitka spruce	1,615.40	1,468.74	1,259.18
Other FC broadleaf	62.34	54.86	40.31
Other FC conifer	374.01	382.52	358.16
WI broadleaf	882.31	746.01	606.54
WI conifer	2,658.32	2,286.49	1,871.07
Thick Peat Soils			
FC Beech	0.02	0.02	0.01
FC Oak	-0.07	-0.06	-0.07
FC Sitka spruce	286.91	254.49	213.31
Other FC broadleaf	4.03	3.14	2.03
Other FC conifer	22.84	26.15	24.85
WI broadleaf	95.55	67.52	42.16
WI conifer	349.88	297.01	236.08
Totals			
FC Beech	176.22	160.57	135.12
FC Oak	162.06	151.87	137.08
FC Sitka spruce	5,002.65	4,513.52	3,874.40
Other FC broadleaf	534.83	478.49	388.31
Other FC conifer	2,052.81	1,981.12	1,826.60
WI broadleaf	13,290.39	11,937.22	10,728.27
WI conifer	10,159.90	8,846.46	7,454.89
All FC woodland	7,928.57	7,285.57	6,361.52
All private woodland	23,450.29	20,783.69	18,183.16