UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities

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Section 1

Key Activities and Results for 2004 – 2005

1. Key activities and results for 2004 – 2005

Land Use Change and Forestry: The 2003 UK Greenhouse Gas Inventory and projections to 2020

- Treatment of losses from soils with conifer afforestation revised. Overall losses have been significantly reduced.
- Soil carbon densities from UK database fully revised. Equilibrium changes in soil carbon due to land use change tend be less when calculated from the revised database.
- Changes to soil carbon stocks with land use change restricted to those occurring in top 1m of soil.
- The Removal of atmospheric CO_2 to Woody Biomass Stocks caused by UK forests in 2003 expansion was estimated to be 9808 Gg CO_2 but there was a source of 248 Gg due to a decrease in the stock of carbon in undecayed forest products from these forests. Removals to Woody Biomass have been varying around 7000 Gg since 1996 but appear now to be on an upward trend. Removals to wood products had been increasing since that date but have now fallen considerably. Removals to Woody Biomass increased from 6014 Gg CO_2 in 1990 to a peak of 7561 Gg CO_2 in 1994, fell to 7137 by 1996 but have now reached a new peak. Removals to products fell from 1587 Gg CO_2 in 1990 to 942 Gg CO_2 in 1994 and were varying around 1200 Gg CO_2 from 1996 to 2000 before the fall to the present source of 248 Gg CO_2.
- Forest soil carbon stocks are now estimated to have increased due to a sink of 5610 Gg CO_2 for 2003. Removals of atmospheric carbon dioxide to the soils of new forests have not varied much over the period 1990 to 2003 but show a peak of 6633 Gg in 1998 followed by a slow downward trend.
- Variation in emissions of greenhouse gases due to deforestation in Great Britain are now included in inventory reports. Emissions are small with a low of 107 Gg CO_2 in 1992 and a high of 297 Gg CO_2 in 1999.
- Estimates of changes in stored soil carbon due to land use change (excluding afforestation) continue to indicate large emissions to the atmosphere although the trend continues downwards. For 2003 the Emission of CO_2 is estimated to be 11565 Gg compared to 13522 Gg in 1990.
- The picture of net emissions in the UK from the Land Use Change and Forestry Sector of the UK has changed significantly due to the data revisions introduced this year. For 1990 the UK remains a net emitter but the value of the emission is now estimated to be 2645 Gg CO_2 made up of 17558 Gg emissions offset by 14913 Gg of removals.
- With the revised data Scotland is shown to be a net remover of atmospheric CO_2 in 1990 because of the combination of enhanced estimates for net removals to the soil of the extensive conifer forest and reduced estimates for losses from the soils of other land.
- England and N. Ireland are estimated to be net emitters in 1990 and Wales a net remover.
- The net CO_2 flux for the UK followed a downward trend, reaching zero between 1997 and 1998 continuing to a net removal of 1536 Gg in 2003. This downward trend is similar but a little less steep than reported in previous inventories
- Data is resented to show emissions and removals for LULUCF in the UK in the reporting format defined by the IPCC Good Practice Guidance for LULUCF

- Projections of Removals and Emissions for the Land Use Change and Forestry Sector up to the year 2020 are presented.
- Estimates of removals and emissions of CO_2 by post-1990 afforestation and deforestation relevant to Article 3.3 of the Kyoto Protocol are presented.
- Estimates of the trend in emissions of CO_2 by Cropland Management and Grassland Management relevant to Article 3.4 of the Kyoto Protocol are presented.

The influence of land use change from and to forestry on the emissions of nitrous oxide and methane

- Data collated on areas of land use change and forestry in UK that may cause emissions of nitrous oxide and methane
- Methods describe in IPCC Good Practice Guidance on LULUCF evaluated and applied to UK
- Results indicate emissions due to these activities are very small in the UK.

Carbon Stock Changes due to Harvested Wood Products: UK

- The EXPHWP spreadsheet model will be useful in calculating carbon flows due to harvested wood products (HWP) in the UK.
- The model provides three methods of calculating carbon flows due to HWP: the Stock-Change Approach, the Atmospheric-Flow Approach and the Production Approach.
- The model uses forestry data from FAOSTAT that is of high quality and regularly updated
- Estimates of the domestic component in HWP production in the Production Approach can be improved
- Results from the EXPHWP model are comparable with those previously produced by CEH using the C-Flow model

Mapping of carbon emissions and removals in the UK due to changes in stocks of soil carbon

- Land use change matrices for each 20km by 20km grid-cell in Great Britain estimated
- Method of modeling changes in soil carbon stocks used at national scales applied to each 20km by 20 km grid-cell in UK
- Good agreement between grid-cell scale totals and national values.

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

- This report details progress that has been made in the development of inventory-based methods for Kyoto Protocol monitoring of forestry based LULUCF activities.

- There is a description of the development of the carbon stock assessment protocol, which will use the updated National Inventory of Woodland and Trees (planned for 2006-2015), including all woods greater than 0.5 ha in area.
- The BSORT model has been applied for carbon stock and stock change assessment, producing estimates for a pilot study area in agreement with national estimates.
- The verification process is described, including an analysis of uncertainty associated with the quantification and use of biomass expansion factors/functions.

Estimating Biogenic Carbon Fluxes from Flux tower measurements and Earth Observation data

- The models used by CTCD to estimate carbon fluxes have been extended to improve the modelling of catchment hydrology.
- A coherence earth observation product from radar-based satellites has been used to produce estimates of the age structure and NEP of all UK forests, with significant differences from inventory-based estimates.
- Improvements have been made in model data assimilation and in the assessment of uncertainties associated with land cover parameterisation and soil carbon stocks.
- Net Ecosystem Productivity and associated uncertainties have been estimated for England and Wales using a dynamic global vegetation model: this will be extended to Scotland in 2005/2006.

Use of Rothamsted Carbon model, RothC, in deriving the UK Carbon inventory

- Investigation has begun of functional forms to describe output from the RothC model that predict in soil carbon stocks due to land use change
- Four functional forms compared to RothC output for Pasture to Arable, Pasture to Semi-natural, Pasture to Forest and Arable to Forest land use transitions.
- An 8 parameter function with 3 exponentials was found to provide a good fit to the all the outputs

RothC-BIOTA v05 plant-soil C turnover model – parameterization and evaluation

- New equilibrium link between RothC and plant growth module.
- Spatial/non spatial functionality of the new coupled model tested.
- Collation of crop parameters.
- Sensitivity tests for spring barley at Hoosfield.
- Improved results of the coupled model in comparison with RothC (Hoosfield).
- Simulation of winter wheat – evaluation continued.

Field Measurements of Soil Carbon Loss following Ploughing

- Eddy covariance measurements of CO_2 flux over ploughed and unploughed fields at Poldean Farm, begun in March 2002, were ended in April 2004. Data analysis is now complete.
- Soil cores taken in November 2003 have now been analysed to give a direct measurement of the change in soil carbon stocks following ploughing.
- The show a highly significant decrease in soil carbon after ploughing ($p < 0.001$). The magnitude of this decrease is 1.15 kg C m^{-2} or 39 % of the initial value (or 0.80 kg C m^{-2} y^{-1} or 27 % y^{-1}, counting 528 days between the date of ploughing and the final soil sampling).
- The direct measurement of soil carbon stock change gives a somewhat higher estimate than the eddy covariance flux measurements (by 0.29 kg C m^{-2} y^{-1}). This is probably caused by the eddy covariance measurements failing to account for fluxes at very high and very low frequencies, and thereby underestimating the flux.

Carbon Balance of Peatlands at Moor House

- Eddy covariance instrumentation was installed at Moor House in the North Penines between 17-25 June 2004.
- The site is an area of extensive blanket peatland and upland grasslands, owned by English Nature. Research at this site dates back to the 1930s, and there is a large body of data from historical and ongoing research.
- The first year's data is presented, which shows characteristic responses of CO2 fluxes to light and temperature.
- The annual land-atmosphere carbon balance is estimated from the measurements, using a simple gap-filling model where observations are unavailable. This gives an annual net flux to be a small source of carbon, of 19 g C m-2.
- These results are provisional because of currently unavailable weather data, and particularly poor data coverage during the first four months of 2005 because of a run of instrument failures and lack of site access because of snow. All data will be re-processed offline over the next year.

Section 2

Land Use Change and Forestry: The 2003 UK Greenhouse Gas Inventory and projections to 2020

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2. Land Use Change and Forestry: The 2003 UK Greenhouse Gas Inventory and projections to 2020

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2.1. Introduction

This sector of the Greenhouse Gas Inventory differs from others in that it contains both sources and sinks of carbon dioxide. The sinks, (or removals), are presented as negative quantities and are reported separately from emissions in the inventory tables. Emissions from land use change and forestry were approximately 2.5% of the UK total in 2003 and are declining gradually.

The estimates for Land Use Change and Forestry are from work carried out by the Centre for Ecology & Hydrology. The data have been submitted using both the new Common Reporting Format tables agreed at the 9th Conference of Parties to the UNFCCC and contained in FCCC/SBSTA/2004/8, and the previous Common Reporting Format under IPCC 1996 Guidelines.

Extensive revision of the data and methods used for this Sector has been made for this Report, starting from the approaches described by Cannell et al. (1999) and Milne and Brown (1999). These revisions have taken into account the recommendations of the IPCC Good Practice Guidance on Land Use, Land Use Change and Forestry (GPG LULUCF) (IPCC, 2003), particularly with respect to land use categories. Section 2.2 contains more detailed descriptions of the methods used to estimate emissions in this Sector.

The structure of this Chapter, and the main submission of CRF Tables is based on the Categories of the IPCC 1996 Guidelines. Each section below includes an account of how the estimates have been used to report under the Categories of the new Common Reporting Format. The Sectoral Report Table 5 in the new CRF format is presented for each year from 1990 to 2003 in Appendix **A.2** and all the CRF Tables for Sector 5 (LULUCF) have been submitted to the UNFCCC using the CRF (LULUCF) Software v1.0. The UK also provided all data for the entire forest sink together, and hence non-forest emissions and removals from soils are provided separately. The activity data and the different groupings are discussed in more detail in Section 2.2.1.(b). Net emissions in 1990 are now estimated to be 2645 Gg CO2 compared to 9050 Gg CO2 in the 2002 National Inventory Report. For 2002 a net removal of –1489 Gg CO2 is estimated here compared to a net emission of 1903 Gg CO2 in the 2002 GHG Inventory.

2.2. LUCF GHG Data on basis of IPCC 1996 Guidelines

2.2.1. Changes in Forests and Other Woody Biomass Stocks

2.2.1.(a) Methodology

The carbon uptake by the forests planted since 1920 is calculated by a carbon accounting model (C-Flow) as the net change in the pools of carbon in standing trees, litter, soil and products from harvested material for conifer and broadleaf forests. The method can be described as Tier 3, as defined in the GPG LULUCF (IPCC, 2003). The model calculates the masses of carbon in the pools of new even-aged plantations that were clearfelled and then replanted at the time of Maximum Area Increment. Activity data are obtained consistently from the same national forestry sources, which ensures time series consistency of estimated removals. The method used for this category has been revised for this Report and recalculations have been made for each year since 1990. This results in an increase in removals of about 40% for each year with some variation due to the pattern of activity.

In the UK all forests can be classified as temperate and about 65% of these have been planted since 1920 on land that had not been forested for many decades. The forests in existence prior to 1920 are considered not to have significant long term changes in biomass stock. This is probably a conservative assumption. The estimates of changes in carbon stock of the forests established since 1920 are based on activity data in the form of annual planting areas of forest published by the UK Forestry Commission and the Northern Ireland Department of Agriculture.

The carbon uptake by the forests planted since 1920 is calculated by a carbon accounting model (Dewar and Cannell, 1992; Cannell and Dewar, 1995; Milne *et al.* 1998) as the net change in pools of carbon in standing trees, litter, soil in conifer and broadleaf forests and products. Restocking is assumed in all forests. The method of the IPCC 1996 Guidelines is not used. The UK carbon accounting model forests calculates the mass of carbon in trees, litter, soil and wood products from harvested material in new even-aged plantations that were clearfelled and then replanted at the time of Maximum Area Increment (MAI). Two types of input data and two parameter sets were required for the model (Cannell and Dewar, 1995). The input data are (a) areas of new forest planted in each year in the past, and (b) the stemwood growth rate and harvesting pattern. Parameter values were required to estimate (i) stemwood, foliage, branch and root masses from the stemwood volume and (ii) the decomposition rates of litter, soil carbon and wood products.

For the estimates described here we used the combined area of new private and state planting from 1920 to 2003 for England, Scotland, Wales and Northern Ireland sub-divided into conifers and broadleaves. Restocking was dealt with in the model through the second and subsequent rotations and hence areas restocked each year did not need to be considered separately. The implicit assumption is therefore that the forests are felled according to standard management tables. Data on variation in management, i.e. felling/replanting dates, from that recommended in the standard tables is not available to the Inventory compilers.

The carbon flow model uses Forestry Commission Yield Tables (Edwards and Christie, 1981) to describe forest growth after thinning and by an expo-linear curve before thinning. It was assumed that all new conifer plantations have the same growth characteristics as Sitka spruce (*Picea sitchensis* (Bong.) Carr.) under an intermediate thinning management. Milne *et al*. (1998) have shown that mean Yield Class for Sitka spruce varied across Great Britain from 10 to 16 m^3 ha^{-1} a^{-1} but with no obvious geographical pattern and that this variation had an effect of less than 10% on estimated carbon uptake for the country as a whole. The Inventory data has therefore been estimated by assuming all conifers in Great Britain follow the growth pattern of Yield Class 12 m^3 ha^{-1} a^{-1}, but in Northern Ireland the Yield Class 14 m^3 ha^{-1} $a^{-1}$is used. Milne *et al.* (1998) also showed that different assumptions for the yield of broadleaf species had little effect on overall carbon uptakes. It is assumed here that broadleaf forests had the characteristics of beech (*Fagus sylvatica* L.) of Yield Class 6 m^3 ha^{-1} a^{-1}. Data in the most recent inventory of British woodlands (Forestry Commission 2002) shows that beech is only about 8% of broadleaf forest (all ages). Sensitivity analysis of the carbon accounting model shows that different assumptions about the broadleaf species planted has little effect on overall carbon uptake; however, the assumption of using beech as the representative species will be reviewed. Using oak or the sycamore-ash-birch group Yield Class data instead of beech data is likely to have a less than 10% effect on the estimated value carbon removal by UK forests. The variation in removals from 1990 to the present is determined by the afforestation rate in earlier decades, irrespective of the species, and the effect that this has on the age structure in the present forest estate, and hence the average growth rate. This afforestation is on ground that has not been wooded for many decades. Table 2-1 shows the afforestation rate since 1922 and the present age structure of these forests. In addition to these planted forests there are about 820,000 ha of woodland that were planted prior to 1922 or are not of commercial importance. Variation from year to year in the reported removals to woody biomass, soils and harvested products reflect the changing pattern of afforestation over the period of available data. For example, there is an increase in removals to harvested products about 50 years after a period of increased planting of conifers, which corresponds to the conifer forest rotation cycle. It can be shown that if forest expansion continues at the present rate then removals of atmospheric carbon will continue to increase until about 2005 and then will begin to decrease, reflecting the reduction in afforestation rate after the 1970s.

Table 2-1 Afforestation rate and age distribution of conifers and broadleaves in the United Kingdom since 1922

	Planting rate (000 ha a^{-1})		Age distribution	
	Conifers	Broadleaves	Conifers	Broadleaves
1922-1929	4.9	2.4	2.9%	6.9%
1930-1939	7.2	2.2	5.3%	8.1%
1940-1949	6.3	1.9	4.6%	6.9%
1950-1959	20.0	3.0	14.8%	11.1%
1960-1969	28.4	2.9	21.0%	10.7%
1970-1979	33.2	1.5	24.6%	5.5%
1980-1989	22.5	1.4	16.7%	5.1%
1990	26.8	3.1	2.0%	1.1%
1991	15.4	5.8	1.1%	2.1%
1992	13.4	6.8	1.0%	2.5%
1993	11.6	6.5	0.9%	2.4%
1994	10.1	8.9	0.7%	3.2%
1995	7.4	11.2	0.5%	4.1%
1996	9.5	10.5	0.7%	3.8%
1997	7.4	8.9	0.6%	3.3%
1998	7.0	9.7	0.5%	3.6%
1999	6.6	10.1	0.5%	3.7%
2000	6.5	10.9	0.5%	4.0%
2001	4.9	13.4	0.4%	4.9%
2002	3.9	10.0	0.3%	3.7%
2003	3.7	9.3	0.3%	3.4%

Increases in stemwood volume were based on standard Yield Tables, as in Dewar and Cannell (1992) and Cannell and Dewar (1995). This pattern of increase in stemwood volume between planting and first thinning has been revised for this year’s submission. The Tables do not provide information for years prior to first thinning so a growth curve was developed to bridge the gap (Hargreaves *et al*. 2003). The pattern fitted to the stemwood volume follows a smooth curve from planting to first thinning. The curve begins with an exponential pattern but progresses to a linear trend that merges with the pattern in forest management tables after first thinning.

The mass of carbon in a forest was calculated from volume by multiplying by species specific wood density, stem:branch and stem:root mass ratios and the fraction of wood carbon content (0.5 assumed). The values used for these parameters for conifers and broadleaves are given in Table 2-2. These parameters also control the transfer of carbon into the litter pools and its subsequent decay. Litter transfer rate from foliage and fine roots increases to a maximum at canopy closure. A fraction of the litter is assumed to decay each year, half of which is added to the soil organic matter pool that then decays at a slower rate. Tree species and Yield Class, rather than other factors that vary with location, are assumed to control the decay of litter and soil matter. Additional litter is generated at times of thinning and felling.

Table 2-2 Main parameters for forest carbon flow model for species used to estimates carbon uptake by planting of forests of Sitka spruce (P. sitchensis) and beech (F. sylvatica) in United Kingdom (data from Dewar & Cannell, 1992)

	P. sitchensis	***P. sitchensis***	***F. sylvatica***
	YC12	**YC14**	**YC6**
Rotation (years)	59	57	92
Initial spacing (m)	2	2	1.2
Year of first thinning	25	23	30
Stemwood density (t m^{-3})	0.36	0.35	0.55
Max. carbon in foliage (t ha^{-1})	5.4	6.3	1.8
Max. carbon in fine roots (t ha^{-1})	2.7	2.7	2.7
Fraction of wood in branches	0.09	0.09	0.18
Fraction of wood in woody roots	0.19	0.19	0.16
Max. foliage litterfall (t ha^{-1} a^{-1})	1.1	1.3	2
Max. fine root litter loss (t ha^{-1} a^{-1})	2.7	2.7	2.7
Dead foliage decay rate (a^{-1})	1	1	3
Dead wood decay rate (a^{-1})	0.06	0.06	0.04
Dead fine root decay rate (a^{-1})	1.5	1.5	1.5
Soil organic carbon decay rate (a^{-1})	0.03	0.03	0.03
Fraction of litter lost to soil organic matter	0.5	0.5	0.5
Lifetime of wood products	57	59	92

Estimates of carbon losses from the afforested soils are based on measurements taken at deep peat moorland locations, covering afforestation of peat from 1 to 9 years previously and at a 26 year old conifer forest (Hargreaves *et al*. 2003). These measurements suggest that long term losses from afforested peatlands are not as great as had been previously thought, settling to about 0.3 t C ha^{-1} a^{-1} thirty years after afforestation. In addition a short burst of regrowth of moorland plant species occurs before forest canopy closure. The pattern of carbon loss and gain from afforested deep peat moorland is summarized in Table 2-3

Carbon incorporated into the soil under all new forests is included and losses from pre-existing soil layers are described by the general pattern measured for afforestation of deep peat with conifers. The relative amounts of afforestation on deep peat and other soils in the decades since 1920 are taken into account. For planting on organo-mineral and mineral soils it is assumed that the pattern of emissions after planting will follow that measured for peat, but the emissions from the pre-existing soil layers will broadly be in proportion to the soil carbon density of the top 30 cm relative to the same depth of deep peat. The choice of proportionality factors was simplified: by assuming that emissions from pre-existing soil layers will be equal to those from the field measurements for all planting in Scotland and Northern Ireland and for conifer planting on peat in England and Wales. Losses from broadleaf planting in England and Wales are, however, assumed to proceed at half the rate of the field measurements. These assumptions are based on consideration of mean soil carbon densities for non-forest in the fully revised UK soil carbon database. However, the temporary re-growth of grasses is assumed to occur for all planting at the same rate as in afforested peat moorland. This assumption agrees with qualitative field observations at plantings on agricultural land in England. As a first approach to quantifying fluxes of carbon dioxide after establishment of forests these assumptions are reasonable at the national scale but further work will be needed to account for variation in soil carbon densities, establishment methods and ground vegetation management between different tree species in different locations. This would be particularly the case where carbon accounting of specific projects or policies are required.

Table 2-3. Emissions of carbon from deep peat due to ploughing for afforestation.(Negative values mean uptake of carbon from the atmosphere. Here this is due to temporary re-growth of moorland plants between ploughing and forest canopy closure. (Based on work of Hargreaves *et al*. 2003).

Years after afforestation	**Carbon loss ($tC\ ha^{-1}\ a^{-1}$)**
0	0.0
1	2.2
2	3.8
3	2.5
4	1.1
5	-0.3
6	-1.2
7	-1.6
8	-1.6
9	-1.3
10	-1.1
15	-0.2
20	0.1
25	0.2
30	0.3

In Inventory submissions prior to 2005 emissions and removals of carbon from soils after afforestation were treated more simply. For broadleaves the reported data included the new carbon accumulating in the afforested area and assumed that emissions from pre-existing soil layers were negligible. For conifers on peaty and mineral soils it was assumed that the newly accumulating soil carbon would exactly balance the emissions due to disturbance from pre-existing soil layers but that there would be an additional emission from afforested areas of deep peat. This latter emission was previously reported under Category 5D or 5E as “Upland drainage” but is no longer relevant due to the more consistent approach for all planting described above. With the smaller estimates of loss from pre-existing soil introduced with the enhanced removals to conifer forests there is a significant increase overall in the net level of removals of atmospheric carbon dioxide to forest soils.

In the carbon accounting model it is assumed that harvested material from thinning and felling is made into wood products. These products then decay over a period equal to the rotation of the forest, conifer or broadleaf as appropriate, since products from broadleaves (e.g. furniture) will decay more slowly than those from conifers (e.g. paper, building timber). The net change in the carbon in this pool of wood products is reported in Category 5A. This method of calculation indicates that part of the total wood products pool from UK forests is presently increasing due to continuing expansion in forest area. Dewar and Cannell (1992) and Cannell and Dewar (1995) provide a detailed description of all the assumptions in the model.

2.2.1.(b) Data Reporting

2.2.1.(b) i - National Inventory Reports

Removals to litter and soil for the afforested areas are reported in the 5A2 Category with changes in forest biomass stocks. Changes in stocks of harvested wood products are also included in this Category

2.2.1.(b) ii - Common Reporting Format under IPCC 1996 Guidelines

Removals due to changes in forest biomass stocks are reported in the 5A2 category but removals to litter and soil for the afforested areas are reported under CRF Category 5D4 (Forest Soils). Changes in stocks of harvested wood products are reported separately under Category 5A5.

2.2.1.(b) iii - Common Reporting Format under IPCC LULUCF Good Practice Guidance

The data for afforestation have been entered in Sectoral Background Table 5.A in the FCCC/SBSTA/2004/8 format (i.e. as recommended in IPCC LULUCF Good Practice Guidance) In Table 5.A.2 (Land converted to Forest Land) the data are disaggregated into afforestation of Cropland, Grassland and Settlements and further by (a) the four geographical areas of England, Scotland, Wales and Northern Ireland, and (b) three time periods, 1920 – 1949, 1950-1979 & 1980 onwards. The removals due to carbon stock changes in harvested wood products are entered into Sectoral Report Table 5.G (Other) as “Harvested Wood Products” in the FCCC/SBSTA/2004/8 format.

2.2.1.(c) Source-specific planned improvements

The method for estimating removals and emissions due to afforestation is being developed to provide data for grid cells of 20 x 20 km. Periodically updated forest inventory data will be used rather than annual planting data to drive the new version. This approach is being developed to meet the requirements of the Kyoto Protocol for data more geographically explicit than the national area for reporting removals due to afforestation and deforestation under Article 3.3. The effect of deviations from standard management and externally imposed disturbances will also be accounted for using this approach.

2.2.2. Forest and Grassland Conversion - Temperate Forests (5B2)

2.2.2.(a) Methodology

In National Inventory Reports and CRF submissions prior to 2002, it was assumed that permanent conversion of forest to non-forest in the UK was negligible. This assumption was based on government guidelines against deforestation, including the need for approval for any permanent forest felling from the Forestry Commission or equivalent in Northern Ireland. Review of this assumption suggested that some deforestation was occurring, and several data sources were examined to estimate the rate quantitatively (Levy and Milne, 2004). This work suggested the approach of combining Forestry Commission unconditional felling licence data for rural areas with Ordnance Survey data for non-rural areas, to reduce suspected biases and inconsistencies in the available data sources. A mean deforestation rate of 1633 ha a^{-1} was estimated for the period 1990 to 1999 and the associated emissions for 1990 to 2002 in the GHG

Inventory submitted in 2004 were each derived from this mean. This approach has now been revised to provide annual figures for the period 1990 to 2003.

In Great Britain, some activities that involve tree felling require permission from the Forestry Commission, in the form of a felling licence, or a felling application within the Woodland Grant Scheme. Under the Forestry Act 1967, there is a presumption that the felled areas will be restocked, usually by replanting. Thus, in the 1990s, ~14,000 ha a^{-1} were felled and restocked. However, some licences are granted without the requirement to restock, where there is good reason – so-called unconditional felling licences. Most of these areas are small (1–20 ha), but their summation gives some indication of deforested area. These areas are not published, but recent figures from the Forestry Commission have been collated. These provide estimates of rural deforestation rates in England for 1990 to 2002 and for GB in 1999 to 2001.

Only local planning authorities hold documentation for allowed felling for urban development and the need for collation makes it difficult to estimate the national total. However, in England, The Ordnance Survey (national mapping agency) makes an annual assessment of land use change (Office of The Deputy Prime Minister, 2003) from data it collects for map updating. Eleven broad land-use categories are defined, with a number of sub-categories. The data for England (1990 to 2002) were used to produce a land-use change matrix, quantifying the transitions between land-use classes. Deforestation rate was calculated as the sum of transitions from all forest classes to all non-forest classes, providing estimates of non-rural deforestation.

The rural and non-rural deforestation values for England were each scaled up to GB scale, assuming that England accounted for 72 per cent of deforestation, based on the distribution of licenced felling between England and the rest of GB in 1999 to 2001. However, the Ordnance Survey data come from a continuous rolling survey programme, both on the ground and from aerial photography. The changes reported each year may have actually occurred in any of the preceding 1-5 years (the survey frequency varies among areas, and can be up to 10 years for moorland/mountain areas). Consequently, a three-year moving average was applied to the data to smooth out the between-year variation appropriately, to give a suitable estimate with annual resolution. The most recent deforestation rate available (1134 ha a^{-1} for 2002) is made up of 243 ha a^{-1} from non-rural areas and 891 ha a^{-1} from rural areas. The rate for 2003 was estimated by extrapolating forwards from the rates for 1999 to 2002. Deforestation is not currently estimated for Northern Ireland. The annual area loss rates were used in the method described in the IPCC 1996 guidelines (IPCC 1997 a, b, c) to estimate immediate emissions of CO_2, CH_4 and N_2O. Only immediate losses are considered because sites are normally completely cleared for development leaving no debris to decay. It is assumed that 60% of the standing biomass is removed as timber products.

The time series consistency of emissions from this sector is only medium given that the two constituent data series are not both available for each year and some are partially derived from data in one region.

2.2.2.(b) Data Reporting

2.2.2.(b) i - National Inventory Reports

The emissions associated with this activity are reported under Source Category 5B2

2.2.2.(b) ii - Common Reporting Format under IPCC 1996 Guidelines

Reported as in National Inventory Report

The data on carbon stock change in biomass from this Category are entered into Sectoral Background Table 5.E.2.1 (Forest Land converted to Settlements) and emissions of CH_4, N_2O, NO_x and CO are entered into the Sectoral Report Table 5 in the CRF tables of the FCCC/SBSTA/2004/8 format. It is assumed that all deforestation is for the purpose of establishment of Settlements. Carbon stock change in soils due to deforestation is dealt with in Category 5D below. In Sectoral Report Table 5 in the FCCC/SBSTA/2004/8 format the Information item “Forest Land converted to other Land-Use Categories” includes both changes in carbon stock in biomass and soils under “Net CO_2 emissions/removals”.

2.2.2.(c) Source-specific planned improvements

Future improvements of the method should include (i) collating Forestry Commission unconditional felling licence data for Scotland and Wales, and (ii) analysing possible causes for the high deforestation rates estimated by OS data for rural areas, which are currently considered too high to be realistic.

2.2.3. CO_2 Emissions and Removals from Soils: Land Use Change

2.2.3.(a) Methodology

Changes in soil stocks due to land use change are estimated in this Category,. All forms of land use change except afforestation are considered together and both mineral and organic soils are included. Removals to soils due to afforestation are considered separately using the forest carbon accounting model described in Section 7.2. The net emissions due to land use change are reported in the previous CRF under Category 5D1 & 5D2 (CO_2 Emissions and Removals from Soils – Cultivation of Mineral & Organic Soils), combined in this and earlier UK NIRs with other Emissions from soils. For this NIR, emissions due to liming of agricultural land are reported separately. Removals due to the effect of Set Aside on soils are now fully reflected in revised land use data and therefore no longer separately estimated or reported.

The basic method for assessing changes in soil carbon due to land use change is to use a matrix of change from land surveys linked to a dynamic model of gain or loss of carbon. For Great Britain (England, Scotland and Wales) matrices from the Monitoring Landscape Change (MLC) data from 1947 and 1980 (MLC 1986) and the Countryside Surveys (CS) of 1984, 1990 and 1998 (Haines-Young *et al.* 2000) are used. In Northern Ireland less data is available to build matrices of land use change but a matrix for the whole of Northern Ireland was available for 1990 to 1998 from the Northern Ireland Countryside Survey (Cooper and McCann, 2002). The only data available pre-1990 for Northern Ireland are land use areas from The Agricultural Census and The Forest Service (2002) , which have been processed by Cruickshank and Tomlinson (2000). Matrices of land use change were then estimated for 1970-79 and 1980-89 using area data. The basis of the method was to assume that the relationship between the matrix of land use transitions for 1990 to 1998 and the area data for 1990 is the same as the relationship between the matrix and area data for each of two earlier periods – 1970-79 and 1980-89. The matrices developed by this approach were used to extrapolate areas of land use transition back to 1950, so as to match the start year in the rest of the UK.

The Good Practice Guidance for Land Use, Land Use Change and Forestry (IPCC, 2003) recommends use of six classes of land for descriptive purposes (e.g. in matrices): Forest, Grassland, Cropland, Settlements, Wetlands and Other Land. The data presently available for the UK does not distinguish wetlands from other types so land in the UK has all been placed into the five other types. The more detailed categories for the two land surveys in Great Britain were combined as shown in Table 2-4 for MLC and Table 2-5 for CS.

Table 2-4 Grouping of MLC land cover types for soil carbon change modelling

CROPLAND	**GRASSLAND**	**FORESTLAND**	**SETTLEMENTS (URBAN)**	**OTHER**
Crops	Upland heath	Broadleaved wood	Built up	Bare rock
Market garden	Upland smooth grass	Conifer wood	Urban open	Sand/shingle
	Upland coarse grass	Mixed wood	Transport	Inland water
	Blanket bog	Orchards	Mineral workings	Coastal water
	Bracken		Derelict	
	Lowland rough grass			
	Lowland heather			
	Gorse			
	Neglected grassland			
	Marsh			
	Improved grassland			
	Rough pasture			
	Peat bog			
	Fresh Marsh			
	Salt Marsh			

Table 2-5 Grouping of Countryside Survey Broad Habitat types for soil carbon change modelling

CROPLAND	**GRASSLAND**	**FORESTLAND**	**SETTLEMENTS (URBAN)**	**OTHER**
Arable	Improved grassland	Broadleaved/mixed	Built up areas	Inland rock
Horticulture	Neutral grassland	Coniferous	Gardens	Supra littoral rock
	Calcareous grassland			Littoral rock
	Acid grassland			Standing waters
	Bracken			Rivers
	Dwarf shrub heath			Sea
	Fen, marsh, swamp			
	Bogs			
	Montane			
	Supra littoral sediment			
	Littoral sediment			

The database of soil carbon density for the UK (Milne and Brown, 1995; Cruickshank *et al.* 1998) used in previous GHG Inventories has been extensively revised recently (Bradley *et al.* 2005). There are three soil survey groups covering the UK and the field data, soil classifications and laboratory methods have been harmonized to reduce uncertainty in the final data. The depth of soil considered was also restricted to 1m at maximum as part of this process. Table 2-6 shows total stock of soil carbon (1990) for different land types in the four devolved areas of the UK.

Table 2-6 Soil carbon stock (TgC = MtC) for depths to 1m in different land types in the UK

Region / Type	**England**	**Scotland**	**Wales**	**N. Ireland**	**UK**
Forestland	108	227	45	20	400
Grassland	995	1,839	283	242	3,359
Cropland	583	110	8	33	734
Settlements	54	10	3	1	69
Other	0	0	0	0	0
TOTAL	**1,740**	**2,187**	**340**	**296**	**4,562**

The effect of land use change from 1950 to the present on stocks of soil carbon is taken into account. Area data exist for various periods between 1947 and 1998 and how these are used is shown in Table 2-7 and Table 2-8. The land use change data over the different periods were used to estimate annual changes by assuming that these were uniform across the measurement period. Examples of these annual changes (for the period 1990 to 1999) are given in Table 2-9 to Table 2-12**.** The data for afforestation and deforestation shown in the Tables are adjusted before use for estimating carbon changes to harmonise the values with those used in the calculations described in Sections 2.2 and **2.3**.

Table 2-7 Sources of land use change data in Great Britain for different periods in estimation of changes in soil carbon.

Year or Period	**Method**	**Change matrix data**
1950-1979	Measured LUC matrix	MLC 1947->MLC1980
1980 - 1984	*Interpolated*	*CS1984->CS1990*
1984 - 1989	Measured LUC matrix	CS1984->CS1990
1990 - 1998	Measured LUC matrix	CS1990->CS1998
1999-2003	*Extrapolated*	*CS1990->CS1998*

Table 2-8 Sources of land use change data in Northern Ireland for different periods in estimation of changes in soil carbon. (NICS = Northern Ireland Countryside Survey)

Year or Period	**Method**	**Change matrix data**
1950 - 1969	*Extrapolation and ratio method*	*NICS1990->NICS1998*
1970 - 1989	*Land use areas and ratio method*	*NICS1990->NICS1998*
1990 - 1998	Measured LUC matrix	NICS1990->NICS1998
1999-2003	*Extrapolated*	*NICS1990->NICS1998*

The core equation describing changes in soil carbon with time for any land use transition is

$$C_t = C_f - (C_f - C_0)e^{-kt}$$

C_t is carbon density at time t
C_0 is initial carbon density
C_f is carbon density after the change to new land use
k is time constant of change

By differentiating we obtain the equation for flux f_t (emission or removal) per unit area

$$f_t = k(C_f - C_o)e^{-kt}$$

From this equation we obtain, for any inventory year, the land use change effects from any specific year in the past. If A_T is area in a particular land use transition in year T considered from 1950 onwards then total carbon lost or gained in an inventory year, e.g. 1990, is given by:

$$F_{1990} = \sum_{T=1950}^{t=1990} kA_T(C_f - C_o)(e^{-k(1990-T)})$$

This equation is used with k, A_T and (C_f-C_0) chosen by Monte Carlo methods within ranges set by prior knowledge e.g. literature, soil carbon database, agricultural census, and LUC matrices

The land use transitions considered are each of those between the Forestland, Grassland, Cropland and Settlement types . It is assumed there are no conversions between these and Other Land. Scotland, England, Northern Ireland and Wales are treated separately.

Table 2-9 Annual changes (000 ha) in land use in England in matrix form for 1990 to 1999. Based on land use change between 1990 and 1998 from Countryside Surveys (Haines-Young *et al.* 2000). Data have been rounded to 100 ha.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland		8.9	3.4	2.1
Grassland	8.7		55.3	3.4
Cropland	0.5	62.9		0.6
Settlements	1.2	8.5	2.1	

Table 2-10 Annual changes (000 ha) in land use in Scotland in matrix form for 1990 to 1999. Based on land use change between 1990 and 1998 from Countryside Surveys (Haines-Young *et al.* 2000). Data have been rounded to 100 ha.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland		11.1	0.6	0.2
Grassland	5.0		16.8	0.7
Cropland	0.1	21.4		0.3
Settlements	0.3	2.2	0.1	

Table 2-11 Annual changes (000 ha) in land use in matrix form for Wales from 1990 to 1999. Based on land use change between 1990 and 1998 from Countryside Surveys (Haines-Young *et al.* 2000). Data have been rounded to 100 ha.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland		2.4	0.2	0.2
Grassland	1.5		5.5	0.6
Cropland	0.0	8.0		0.0
Settlements	0.1	1.8	0.2	

Table 2-12 Annual changes (000 ha) in land use in matrix form for Northern Ireland from 1990 to 1999. Based on land use change between 1990 and 1998 from Northern Ireland Countryside Surveys (Cooper and McCann 2002). Data have been rounded to 100 ha.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland		1.6	0.0	0.0
Grassland	0.3		5.9	0.0
Cropland	0.0	3.7		0.0
Settlements	0.1	1.0	0.0	

In the model, the change is required in equilibrium carbon density from the initial to the final land use during a transition. These are calculated for each land use category as averages for

Scotland, England, Wales and Northern Ireland. These averages are weighted by the area of Land Use Change occurring in four broad soil groups (Organic, organo-mineral, mineral, unclassified) in order to account for the actual carbon density where change has occurred. Hence mean soil carbon density change is calculated as:

$$\overline{C}_{ijc} = \frac{\sum_{s=1}^{6}(C_{sijc}L_{sijc})}{\sum_{s=1}^{6}L_{sijc}}$$

which is the weighted mean, for each country, of change in equilibrium soil carbon when land use changes and

i is initial land use (Forestland, grassland, cropland, settlements),
j is new land use (Forestland, grassland, cropland, settlements),
c is country (Scotland, England, N. Ireland & Wales),
s is soil group (Organic, organo-mineral, mineral, unclassified), and
C_{sijc} is change in equilibrium soil carbon for a specific land use transition

The most recent land use data (1990 to 1998) is used in the weighting. The averages carbon densities calculated are presented in Table 2-13 to Table 2-16**.**

Table 2-13. Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in England.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	25	32	83
Grassland	-21	0	23	79
Cropland	-31	-23	0	52
Settlements	-87	-76	-54	0

Table 2-14. Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Scotland.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	35	133	206
Grassland	-39	0	77	157
Cropland	-140	-78	0	81
Settlements	-200	-156	-62	0

Table 2-15. Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Wales.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	23	57	114
Grassland	-18	0	36	101
Cropland	-53	-38	0	48
Settlements	-110	-95	-73	0

Table 2-16. Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Northern Ireland.

From / To	Forestland	Grassland	Cropland	Settlements
Forestland	0	94	168	244
Grassland	-94	0	74	150
Cropland	-168	-74	0	76
Settlements	-244	-150	-76	0

The rate of loss or gain of carbon is dependent on the type of land use transition (Table 2-17). For transitions where carbon is lost e.g. transition from Grassland to Cropland, a 'fast' rate is applied whilst a transition that gains carbon occurs much more slowly. Information on measured rates of changes of soil carbon due to land use in the literature was used in combination with expert judgement to select ranges of possible times for completion of different transitions. These are shown in Table 2-18.

Table 2-17 Rates of change of soil carbon for land use change transitions. ("Fast" & "Slow" refer to 99% of change occurring in times shown in **Table A3.7.9**

		Initial			
		Cropland	**Grassland**	**Settlement**	**Forestland**
Final	**Cropland**		*slow*	*slow*	*slow*
	Grassland	*fast*		*slow*	*slow*
	Settlement	*fast*	*fast*		*slow*
	Forestland	*fast*	*fast*	*fast*	

Table 2-18 Range of times for soil carbon to reach 99% of a new value after a change in land use in England (E), Scotland (S) and Wales (W).

	Low (years)	**High (years)**
Carbon loss ("fast") E, S, W.	50	150
Carbon gain ("slow") E, W.	100	300
Carbon gain ("slow") S.	300	750

Changes in soil carbon from equilibrium to equilibrium (C_f-C_o) were assumed to fall within ranges based on 2004 database values for each transition and the uncertainty indicated by this source (up to +/-11% of the mean). The areas of land use change for each transition were assumed to fall within a range of uncertainty of +/- 30% of the mean.

The model of change was run 1000 times with each parameter (the time constant for change in soil carbon, land use change areas and equilibrium carbon change) being selected separately using a Monte Carlo approach. This was done for England, Scotland N. Ireland and Wales from within the ranges described above. The mean carbon flux for each region resulting from this imposed random variation is reported as the estimate for the Inventory. An adjustment was made to these calculations for each country to remove increases in soil carbon due to afforestation, as the C-Flow model (See Section 2.2) provides a better estimate of these fluxes.

Variations from year to year in the reported net emissions reflect the trend in land use change as described by the matrices of change.

The methodological revisions introduced for this submission have resulted in a reduction of net emissions in this category, compared to previous submissions, of about 3% for 1990, but an increase of about 25% for 2002.

2.2.3.(b) Data Reporting

2.2.3.(b) i - National Inventory Reports

Emissions and removals for this activity are combined and reported as a net flux under Category 5D.

2.2.3.(b) ii - Common Reporting Format under IPCC 1996 Guidelines

Emissions and removals for this activity for both mineral and organic soils are all combined and reported as a net flux under Category 5D1 (CO_2 Emissions and Removals from Soils: Cultivation of Mineral Soils)

2.2.3.(b) iii - Common Reporting Format under IPCC LULUCF Good Practice Guidance

The data on carbon stock change in soils from this Category are entered into Sectoral Background Table 5.B.2 (Forest Land converted to Cropland), 5.C.2 (Forest Land converted to Grassland) and 5.E.2 (Forest Land converted to Settlements) in the CRF tables of the FCCC/SBSTA/2004/8 format. The data are reported as aggregate values for all land converted to Cropland, Grassland and Settlements, i.e. they are not disaggregated by the original land category. The aggregate data are however disaggregated by (a) the four geographical areas of England, Scotland, Wales and Northern Ireland, and (b) by changes that occurred in the two time periods, 1950-1979 and 1980 onwards. Soil carbon stock changes due to deforestation were identified within the aggregate data in 5.E.2 (Forest Land converted to Settlements) are included with carbon stock changes in biomass from 5.E.2.1 to provide the basis for "Net CO_2 emissions/removals" in the Information item "Forest Land converted to other Land-Use Categories" in Sectoral Report Table 5 in the FCCC/SBSTA/2004/8 format.

2.2.3.(c) Source-specific planned improvements

In the long term, the UK is planning to implement the use of a process-based model for estimating emissions and removals from soils. This method is unlikely to be available for a few years, hence the enhancement of the existing approach.

2.2.4. CO_2 Emissions and Removals from Soils: Forest Soils

2.2.4.(a) Methodology

Removals associated with increases in soil carbon under areas of the UK afforested since 1920 are estimated by the carbon accounting method described in Section 2.2.2. These Removals are however reported under different categories for different requirements as described below

2.2.4.(b) Data Reporting

2.2.4.(b) i - National Inventory Reports

In the NIR the fluxes associated with changes in carbon stocks in forest soils have been included in the 5A2 Category with changes in forest biomass stocks. This approach was that originally used by the UK and is now seen to be consistent with that in the LULUCF Good Practice Guidance.

2.2.4.(b) ii - Common Reporting Format under IPCC 1996 Guidelines

In reporting to the UNFCCC under the IPCC 1996 Guidelines these removals to soil are identified under CRF Category 5D4 (Forest Soils),

2.2.4.(b) iii - Common Reporting Format under IPCC LULUCF Good Practice Guidance

The emissions in this Category are entered into Sectoral Background Table 5.A.2 (Land converted to Forest Land) in the CRF tables of the FCCC/SBSTA/2004/8 format. The data in that table are disaggregated as described above for Source Category: Changes in Forests and Other Woody Biomass Stocks.

2.2.5. CO_2 Emissions and Removals from Soils: Emissions of CO_2 from soil due to liming

2.2.5.(a) Methodology

Emissions of carbon dioxide from the application of limestone, chalk and dolomite to agricultural soils were estimated using the method described in the IPCC 1996 Guidelines. Data on the use of limestone, chalk and dolomite for agricultural purposes is reported in BG S (2004). They also include ‘material for calcination’. In agriculture all three minerals are applied to the soil, and CO_2 emissions, weight for weight, from limestone and chalk will be identical since they have the same chemical formula. Dolomite, however, will have a slightly higher emission due to the presence of Mg. For limestone and chalk, an emission factor of 120 tC kt^{-1} applied is used, and for dolomite application, 130 tC kt^{-1}. These factors are based on the stoichiometry of the reaction and assume pure limestone/chalk and dolomite (IPCC, 1997a, b, c). Only dolomite is subjected to calcination. However, some of this calcinated dolomite is not suitable for steel making and is returned for inclusion with agricultural dolomite – this fraction is reported in PA1007 as ‘material for calcination’ under agricultural end use. Calcinated dolomite, having already had its CO_2 removed, will therefore not cause the emissions of CO_2 and hence is not included here. Lime (calcinated limestone) is also used for carbonatation in the refining of sugar but this is not specifically dealt with in the UK LUCF GHG Inventory.

Estimates of the individual materials had to be made this year as only their total was published because of commercial confidentiality rules for small quantities. It is assumed that all the carbon contained in the materials applied is released in the year of use.

Uncertainty in both the activity data and emission factor used for this source are judged to be low. The main source of uncertainty in the estimates is caused by non-publication of some data due to commercial restrictions, although these are not judged to be very significant. Time-series consistency is underpinned by continuity in data source.

2.2.5.(b) Data Reporting

2.2.5.(b) i - National Inventory Reports

In the NIR the emissions of CO_2 due to liming are combined with emissions from soils due to land use change and this total is reported under Category 5D (CO_2 Emissions and Removals from Soils

2.2.5.(b) ii - Common Reporting Format under IPCC 1996 Guidelines

For reporting to the UNFCCC under the IPCC 1996 Guidelines the emissions are identified separately under Category 5D3 (CO_2 Emissions and Removals from Soils: Liming of Agricultural Soils)

2.2.5.(b) iii - Common Reporting Format under IPCC LULUCF Good Practice Guidance

The emissions in this Category are entered into Sectoral Background Table 5 (IV) (Carbon emissions from agricultural lime application) in the CRF tables of the FCCC/SBSTA/2004/8 format. The data in that table are disaggregated by application of limestone and dolomite separately on either Cropland or Grassland.

2.2.6. Lowland (fen) peat drainage

Lowland wetlands in England were drained many years ago for agricultural purposes and continue to emit CO_2 from the soil. This management activity is not modelled by the broad scale approach to land use change described in Section 2.2.1 and separate estimates of recent emissions have been included here. Bradley (1997) described the methods used to estimate these emissions. The baseline (1990) for the area of drained lowland wetland for the UK was taken as 150,000 ha. This represents all of the East Anglian Fen and Skirtland and limited areas in the rest of England. This total consists of 24,000 ha of land with thick peat (more than 1m deep) and the rest with thinner peat. Different loss rates were assumed for these two thicknesses as shown in Table 2-19.

Table 2-19 Area and carbon loss rates of UK fen wetland in 1990

	Area	**Organic carbon content**	**Bulk density**	**Volume loss rate**	**Carbon mass loss**	**Implied emission factor**
			kg m^{-3}	**m^3 m^{-2} a^{-1}**	**GgC a^{-1}**	**gC m^{-2} a^{-1}**
‘Thick’ peat	24x107 m2 (24,000 ha)	21%	480	0.0127	307	1280
‘Thin’ peat	126×10^7 m^2 (126,000 ha)	12%	480	0.0019	138	109
Total	150×10^7 m^2 (150 kha)				445	297

The trend in emissions after 1990 was estimated on the assumption that no more area has been drained since then but the existing areas have continued to lose carbon. The annual loss decreases for a specific location in proportion to the amount of carbon remaining. But, in addition to this, as the peat loses carbon it will become more mineral in structure. Burton (1995) provides data on how these soil structure changes proceed with time. The Century model of plant and soil carbon was used to average the carbon losses for the areas of component soils as they thinned to lose peat, become humose and possibly even mineral (Bradley 1997).

2.2.6.(a) Data Reporting

2.2.6.(a) i - National Inventory Reports

Emission of CO_2 from drained lowland fens are reported in Category 5E (Other) in National Inventory Reports.

2.2.6.(a) ii - Common Reporting Format under IPCC 1996 Guidelines

Emission of CO_2 from drained lowland fens are reported in Category 5D5 (CO_2 Emissions and Removals - Other) in submissions to the UNFCCC under the IPCC 1996 Guidelines

2.2.6.(a) iii - Common Reporting Format under IPCC LULUCF Good Practice Guidance

The emissions in this Category (due to lowland drainage) are entered into Sectoral Background Table 5.B.1 (Cropland remaining Cropland) in the CRF tables of the FCCC/SBSTA/2004/8 format.

2.2.7. Changes in Non-forest Biomass

2.2.7.(a) Methodology

This includes annual changes in the biomass of vegetation in the UK due to all land use change but excludes forests and woodland. Much of this change involves changes to or from agricultural crops, hence the previous use of the term “crop biomass” for this activity.

Adger and Subak (1996) estimated recent changes in carbon storage in biomass on non-forest lands in the UK, including land used for agriculture, horticulture and urbanization. The land area converted to forest was specifically excluded to avoid overlap with estimates for Category 5A and 5B. They used agricultural census statistics for the period 1988-1992 published by the Ministry of Agriculture, Fisheries and Food. These statistics are strongly correlated with agricultural land cover data in 1984 and 1990 UK Countryside Surveys, which were used to calculate changes in soil carbon on non-forest lands, so the two estimates are considered to be compatible.

Two carbon sinks were quantified. First, 0.23 MtC a^{-1} was estimated to be accumulating in biomass as a result, mainly, of (i) the transfer of land from arable crops with 2.2 tC ha^{-1} biomass to set aside land with 5.0 tC ha^{-1} biomass, (ii) the establishment of woodlands on farms in response to financial incentives (Farm Woodland Scheme and Farm Woodland Premium), assuming that these woodlands increased in biomass by 2.8 tC ha^{-1} a^{-1}, (iii) the transfer of agricultural land to urban uses, assuming that urban land has an average carbon density of 3 tC ha^{-1} and (iv) the transfer of rough grass to permanent grass.

Second, 0.14 MtC a^{-1} was estimated to be accumulating on agricultural land, without a change in crop type, on the assumption that the annual average standing biomass has increased linearly with yield. Most of this component was due to increases in cereal yields.

Thus, the total increase in biomass on agricultural land was estimated to be 0.37 MtC a^{-1}. However, this is an upper bound, because some of the farm woodlands were also counted in Forestry Commission statistics which were used to calculate the forest biomass carbon for Category 5A, and because increases in `harvest index' mean that crop biomass generally increases proportionately less than yield. Thus, the lower estimate for this component of 0.3 MtC a^{-1} ±30% has been adopted for non-forest biomass changes. From the 1998 Inventory onwards more recent data from the Agricultural Census were considered but did not support any change to the existing estimate. This rate is therefore reported for all years from 1990 to 2003.

2.2.7.(b) Data Reporting

2.2.7.(b) i - National Inventory Reports

Removals of CO_2 due to changes in stocks of non-forest carbon are reported in Category 5E (Other) in National Inventory Reports.

2.2.7.(b) ii - Common Reporting Format under IPCC 1996 Guidelines

Removals of CO_2 due to changes in stocks of non-forest biomass carbon are reported in Category 5E (Other) in submissions to the UNFCCC under the IPCC 1996 Guidelines.

2.2.7.(b) iii - Common Reporting Format under IPCC LULUCF Good Practice Guidance

In the CRF tables of the FCCC/SBSTA/2004/8 format the removals due to carbon stock changes in non-forest biomass are entered into Sectoral Report Table in 5.G (Other) as "Changes in non-forest biomass".

2.2.7.(c) Source-specific planned improvements

A review of the approaches taken in for this activity will be made in terms of input data and appropriateness of reporting category

2.2.8. Peat Extraction

Peat is extracted in the UK for use as either a fuel or in horticulture. Estimates are made separately for each of these end uses

Cruickshank *et al.* (1997) provide initial estimates of Emissions due to peat extraction. Since their work trends in peat extraction in Scotland and England over the period 1990 to 2003 have been estimated from activity data taken from the UK Minerals Handbook (BGS 2004). In Northern Ireland no new data on use of peat for horticultural use has become available but a recent survey of extraction for fuel use suggested that there is no significant trend for this use. The contribution of emissions due to peat extraction in Northern Ireland is therefore incorporated as constant from 1990 to 2003. Peat extraction is negligible in Wales. Emissions factors are from Cruickshank *et al.* (1997) and are shown in Table 2-20.

Table 2-20 Emission Factors for Peat Extraction (GB Great Britain, NI Northern Ireland)

	Emission Factor	
	kg C m^{-3}	Gg C Gg^{-1}
GB Horticultural Peat	55.7	-
GB Fuel Peat	55.7	-
NI Horticultural Peat	44.1	-
NI Fuel Peat	-	0.3

Activity data for peat extraction come from a number of sources, only some of which are reliable, which will have some effect on time series consistency.

2.2.8.(a) Data Reporting

2.2.8.(a) i - National Inventory Reports

Emissions of CO_2 due to peat extraction are reported in Category 5E (Other) in National Inventory Reports.

2.2.8.(a) ii - Common Reporting Format under IPCC 1996 Guidelines

Removals of CO_2 due to peat extraction are reported in Category 5E (Other) in submissions to the UNFCCC under the IPCC 1996 Guidelines.

2.2.8.(a) iii - Common Reporting Format under IPCC LULUCF Good Practice Guidance

In the CRF tables of the FCCC/SBSTA/2004/8 format the emissions in this Category due to peat extraction are entered into Sectoral Background Table 5.C.1 (Grassland remaining Grassland).

2.2.8.(b) Source-specific planned improvements

The data for this activity include some emissions due to use of extracted peat as a fuel. The relationship between this data and emissions estimated by other agencies for the Energy Sector of the GHG Inventory will be reviewed.

2.2.9. Activities no longer used

2.2.9.(a) Upland drainage

This source, which is due to the ploughing and drainage of deep peat for the purposes of establishment of new forests, is no longer reported. Losses from deep peat afforestation are now estimated within the forest carbon accounting model as described in Section 2.2.2.

2.2.9.(b) Set Aside

Various schemes for arable land to be set aside from agricultural production have been in place in the UK since 1990. A separate estimate was made of the changes in stocks of soil carbon (a net sink) due to set aside of arable land in previous UK GHG Inventories because the land use change data available were extrapolated from data collected before 1990. The effect of this activity is now estimated within the methods of Section 2.2.3 for assessing the effect of all land use change on soil carbon stocks. This has become possible due to the availability of post-1990 land use change data.

2.2.10. Summary Tables

The UK provides the National Inventory data for the entire forest sink together, and non-forest emissions and removals from soils in a separate group. This provides a broad separation of sinks and sources within the LUCF sector. This approach is not that taken by the UNFCCC Common Reporting Format based on the IPCC 1996 Guidelines, within which all soil fluxes (forest and non-forest) are reported together. Table 2-21**,** Table 2-22**,** Table 2-23 and Table 2-24 show the activities concerned and how they have been combined in the different ways. The reported totals for emissions and removals for the LUCF Sector are not affected.

The UK has also prepared the data in the format and tables described in FCCC/SBSTA/2004/8 as adopted at COP9 and based on the LULUCF Good Practice Guidance (IPCC, 2003) (Table 2-25). The Sectoral Report Tables for each year from 1990 to 2003 in this new CRF format are included here in Appendix A.3.

Approximate uncertainty for different activities is shown in Table 2-26.

Table 2-21 Categories used for reporting soils emissions and removals

Process	**National Inventory Report**	**Common Reporting Format (IPCC 1996 Guidelines)**
Removals to forest soils and litter	5A2 (Removal)	5D (Removal)
Emissions from soils due to lowland drainage	5E (Emission)	5D (Emission)

Table 2-22 Emissions and removals of carbon dioxide by activities in Land Use Change and Forestry Sector. The reporting categories used in the National Inventory Report (NIR) and for the UNFCCC Common Reporting Format based on the IPCC 1996 Guidelines are also shown. (IE - Included Elsewhere.)

Activity	**Gg CO_2**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**NIR**	**CRF**
Temperate forest	Removal	-6014	-6486	-6950	-7215	-7561	-7245	-7137	-6927	-6827	-7171	-6856	-7776	-8916	-9808	*5A2*	*5A2*
Harvested wood	Removal	-1587	-1344	-1130	-1059	-942	-1123	-1098	-1195	-1289	-1161	-1314	-743	-133	248	*5A5*	*5A5*
Deforestation	Emission	164	137	107	124	132	161	185	152	159	297	223	228	180	141	*5B*	*5B*
Mineral soils	Emission	13522	13326	13139	12961	12791	12630	12475	12327	12186	12050	11922	11798	11679	11565	*5D*	*5D*
Mineral soils	Removal	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	*5D*	*5D*
Organic soils	Emission	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	*5D*	*5D*
Organic soils	Removal	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	*5D*	*5D*
Liming	Emission	1430	1772	1810	1130	1270	1529	1515	1346	1058	887	794	725	739	918	*5D*	*5D*
Forest soils	Removal	-6211	-6131	-6168	-6263	-6297	-6483	-6524	-6601	-6633	-6494	-6556	-6233	-5859	-5610	*5A2*	*5D*
Lowland Drainage	Emission	1650	1613	1577	1540	1503	1467	1430	1393	1357	1320	1283	1261	1239	1217	*5E*	*5D*
Peat extraction	Emission	792	803	792	781	889	950	869	815	704	822	816	855	683	894	*5E*	*5E*
Changes in non-forest biomass	Removal	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	*5E*	*5E*

Table 2-23 Emissions and removals in categories with the Land Use Change and Forestry Sector as reported in the format used for the National Inventory Report. (IE - Included Elsewhere.)

NIR	**Gg CO_2**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	***Category***	
Temperate forest	Removal	-12226	-12616	-13118	-13478	-13858	-13727	-13661	-13527	-13459	-13665	-13411	-14009	-14775	-15418	*5A2*	Sum of Removals due to Changes in Forest biomass, Forest litter & soils
Harvested wood	Removal	-1587	-1344	-1130	-1059	-942	-1123	-1098	-1195	-1289	-1161	-1314	-743	-133	248	*5A5*	Removals to Harvested wood
Deforestation	Emission	164	137	107	124	132	161	185	152	159	297	223	228	180	141	*5B*	Emissions (CO_2) due to Deforestation
Soils	Emission	14952	15098	14948	14091	14061	14159	13990	13674	13244	12937	12716	12522	12418	12482	*5D*	Sum of Emissions from soils and Removals to soils due to Land use change (not forestry), and Liming of agricultural land
	Emission	*13522*	*13326*	*13139*	*12961*	*12791*	*12630*	*12475*	*12327*	*12186*	*12050*	*11922*	*11798*	*11679*	*11565*		*Land use change*
	Emission	*1430*	*1772*	*1810*	*1130*	*1270*	*1529*	*1515*	*1346*	*1058*	*887*	*794*	*725*	*739*	*918*		*Liming*
Soils	Removal	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE		*5D*	Included in Emission
Other	Emission	2442	2416	2368	2321	2392	2417	2299	2208	2060	2142	2099	2116	1922	2111	*5E*	Sum of Emissions from soils due to Lowland drainage and Peat extraction
	Emission	*1650*	*1613*	*1577*	*1540*	*1503*	*1467*	*1430*	*1393*	*1357*	*1320*	*1283*	*1261*	*1239*	*1217*		*Lowland drainage*
	Emission	*792*	*803*	*792*	*781*	*889*	*950*	*869*	*815*	*704*	*822*	*816*	*855*	*683*	*894*		*Peat extraction*
Other	Removal	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	*5E*	Removals due to changes in non-forest biomass
Total	Emission	17558	17650	17424	16536	16585	16737	16474	16034	15463	15376	15038	14866	14520	14734	*5*	Gross LUCF Emissions
Total	Removal	-14913	-15061	-15348	-15637	-15900	-15950	-15859	-15823	-15849	-15926	-15826	-15852	-16008	-16270	*5*	Gross LUCF Removals
Total	Net	2645	2590	2076	899	685	787	616	211	-385	-550	-787	-986	-1489	-1536	*5*	Net LUCF Emissions

Table 2-24 Emissions and removals in categories with the Land Use Change and Forestry Sector as reported in the format used for the UNFCCC Common Reporting Format based on the IPCC 1996 Guidelines. (IE - Included Elsewhere.)

CRF	**Gg CO_2**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	***Category***	
Temperate forest	Removal	-6014	-6486	-6950	-7215	-7561	-7245	-7137	-6927	-6827	-7171	-6856	-7776	-8916	-9808	*5A2*	Removals due to Changes in forest biomass.
Harvested wood	Removal	-1587	-1344	-1130	-1059	-942	-1123	-1098	-1195	-1289	-1161	-1314	-743	-133	248	*5A5*	Removals to Harvested wood
Deforestation	Emission	164	137	107	124	132	161	185	152	159	297	223	228	180	141	*5B*	Emissions (CO_2) due to Deforestation
Soils	Emission	16602	16711	16525	15631	15565	15626	15420	15067	14601	14257	13999	13784	13657	13700	*5D*	Sum of Emissions from soils due to Land use change on agricultural soils (net emissions), Lowland drainage and liming of agricultural land
	Emission	*13522*	*13326*	*13139*	*12961*	*12791*	*12630*	*12475*	*12327*	*12186*	*12050*	*11922*	*11798*	*11679*	*11565*		*Land use change*
	Emission	*1650*	*1613*	*1577*	*1540*	*1503*	*1467*	*1430*	*1393*	*1357*	*1320*	*1283*	*1261*	*1239*	*1217*		*Lowland drainage*
	Emission	*1430*	*1772*	*1810*	*1130*	*1270*	*1529*	*1515*	*1346*	*1058*	*887*	*794*	*725*	*739*	*918*		*Liming*
Soils	Removal	-6211	-6131	-6168	-6263	-6297	-6483	-6524	-6601	-6633	-6494	-6556	-6233	-5859	-5610	*5D*	Removals to Forest litter & soils.
Other	Emission	792	803	792	781	889	950	869	815	704	822	816	855	683	894	*5E*	Emissions from soils due to Peat extraction
Other	Removal	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	-1100	*5E*	Removals due to changes in non-forest biomass
Total	Emission	17558	17650	17424	16536	16585	16737	16474	16034	15463	15376	15038	14866	14520	14734	*5*	Gross LUCF Emissions
Total	Removal	-14913	-15061	-15348	-15637	-15900	-15950	-15859	-15823	-15849	-15926	-15826	-15852	-16008	-16270	*5*	Gross LUCF Removals
Total	Net	2645	2590	2076	899	685	787	616	211	-385	-550	-787	-986	-1489	-1536	*5*	Net LUCF Emissions

Table 2-25: Emissions and removals in categories with the Land Use Change and Forestry Sector as reported in the format used for the UNFCCC Common Reporting Format defined by the IPCC LULUCF Good Practice Guidance.

Gg CO_2/year		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
5	**NET**	**2645**	**2590**	**2076**	**899**	**685**	**787**	**616**	**211**	**-385**	**-550**	**-787**	**-986**	**-1489**	**-1536**
5A	**Forest-Land**	**-12226**	**-12616**	**-13118**	**-13478**	**-13858**	**-13727**	**-13661**	**-13527**	**-13459**	**-13665**	**-13411**	**-14009**	**-14775**	**-15418**
5A1	*Forest-Land remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5A2	*Land converted to Forest-*	*-12226*	*-12616*	*-13118*	*-13478*	*-13858*	*-13727*	*-13661*	*-13527*	*-13459*	*-13665*	*-13411*	*-14009*	*-14775*	*-15418*
5B	**Cropland**	**15544**	**15693**	**15681**	**15286**	**15331**	**15442**	**15407**	**15289**	**15108**	**14990**	**14917**	**14870**	**14869**	**14956**
5B1	*Cropland remaining*	*1650*	*1613*	*1577*	*1540*	*1503*	*1467*	*1430*	*1393*	*1357*	*1320*	*1283*	*1261*	*1239*	*1217*
5B2	*Land converted to*	*13127*	*13130*	*13134*	*13140*	*13147*	*13155*	*13164*	*13174*	*13184*	*13195*	*13207*	*13220*	*13233*	*13247*
5B (liming)	*Liming of Cropland*	*767*	*950*	*970*	*606*	*681*	*820*	*812*	*722*	*567*	*476*	*426*	*388*	*396*	*492*
5C	**Grassland**	**-4929**	**-4886**	**-5003**	**-5450**	**-5394**	**-5326**	**-5525**	**-5766**	**-6117**	**-6182**	**-6333**	**-6426**	**-6688**	**-6489**
5C1	*Grassland remaining*	*792*	*803*	*792*	*781*	*889*	*950*	*869*	*815*	*704*	*822*	*816*	*855*	*683*	*894*
5C2	*Land converted to*	*-6384*	*-6511*	*-6634*	*-6754*	*-6872*	*-6986*	*-7097*	*-7206*	*-7312*	*-7415*	*-7517*	*-7617*	*-7714*	*-7809*
5C (liming)	*Liming of Grassland*	*664*	*822*	*839*	*524*	*589*	*709*	*703*	*625*	*491*	*411*	*368*	*336*	*343*	*426*
5D	**Wetland**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	*Wetland remaining*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*
5D2	*Land converted to Wetland*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*
5E	**Settlements**	**6944**	**6844**	**6746**	**6699**	**6647**	**6621**	**6593**	**6511**	**6473**	**6568**	**6455**	**6422**	**6339**	**6268**
5E1	*Settlements remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5E2	*Land converted to*	*6944*	*6844*	*6746*	*6699*	*6647*	*6621*	*6593*	*6511*	*6473*	*6568*	*6455*	*6422*	*6339*	*6268*
5F	**Other-Land**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
5F1	*Other-Land remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5F2	*Land converted to Other-*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5G	**Other activities**	**-2687**	**-2444**	**-2230**	**-2159**	**-2042**	**-2223**	**-2198**	**-2295**	**-2389**	**-2261**	**-2414**	**-1843**	**-1233**	**-852**
5G1	*Harvested Wood Products*	*-1587*	*-1344*	*-1130*	*-1059*	*-942*	*-1123*	*-1098*	*-1195*	*-1289*	*-1161*	*-1314*	*-743*	*-133*	*248*
5G2	*Changes in non-forest*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*	*-1100*
5E2	**Deforestation Gg**	0.716	0.597	0.468	0.540	0.574	0.703	0.807	0.664	0.695	1.295	0.974	0.993	0.784	0.614
5E2	**Deforestation Gg**	0.005	0.004	0.003	0.004	0.004	0.005	0.006	0.005	0.005	0.009	0.007	0.007	0.005	0.004
Included in	**Deforest immediate**	164	137	107	124	132	161	185	152	159	297	223	228	180	141
Included in	**Deforest delayed (Soil)**	578	561	546	531	517	504	491	480	469	458	448	439	430	422

Table 2-26. Approximate uncertainty of estimates of emissions or removals in each of the Categories reported.

Category	5A Changes in Forest Biomass	5B Forest Conversion	5D Soils	5E Other
Uncertainty in Emission/Removal, %	30	20	60	50

2.2.11. Results

The data for the 2003 Inventory and equivalent values for 1990 to 2002 (2005 submission date) can be summarised from Table 2-24. The same data is also presented in Appendix 2 in the Common Reporting Format Table 5 Sectoral Report (IPCC 1996 Guidelines style) and in Appendix 3 in the Common Reporting Format defined by the IPCC LULUCF Good Practice Guidance for each year separately.

2.2.11.(a) Changes in Forest and Other Woody Biomass Stocks

2.2.11.(a) i - Temperate Forest

The Removal of atmospheric CO_2 to Woody Biomass Stocks caused by expanding UK forests in 2003 was estimated to be 9808 Gg but there was a source of 248 Gg due to a decrease in the stock of carbon in undecayed forest products from these forests. Removals to Woody Biomass have been varying around 7000 Gg since 1996 but appear now to be on an upward trend. Removals to wood products had been increasing since that date but have now fallen considerably. Removals to Woody Biomass increased from 6014 Gg in 1990 to a peak of 7561 Gg in 1994, fell to 7137 by 1996 but have now reached a new peak. Removals to products fell from 1587 Gg in 1990 to 942 Gg in 1994 and were varying around 1200 Gg from 1996 to 2000 before the fall to the present source of 248 Gg. These changes reflect variation in planting rates in past decades which feed through growth and felling to the carbon uptake trends reported here. Changes in forest soils are discussed with other processes related to changes in soils.

2.2.11.(b) Forest Conversion

2.2.11.(b) i - Deforestation

Variation in emissions of greenhouse gases due to deforestation in Great Britain are now included in inventory reports. Emissions are small with a low of 107 Gg CO_2 in 1992 and a high of 297 Gg in 1999. Emissions of CH_4 and N_2O follow the same pattern as CO_2 (see Table 2-25).

2.2.11.(c) CO_2 Emissions and Removals from Soil

2.2.11.(c) i - Land use change

Estimates of changes in stored soil carbon due to land use change (excluding afforestation) continue to indicate large emissions to the atmosphere although the trend continues downwards. For 2003 the Emission of CO_2 is estimated to be 11565 Gg compared to 13522 Gg in 1990. The revisions to the soil carbon database, availability of more recent land use change areas and removal of the very uncertain data for peat deeper than 1m have had a greater effect on estimated emissions from Scotland compared to the other regions. The calculations now suggest that emissions in England make up about half of the UK total and Scotland about one third. Land use changes on both mineral and organic soils are included in these estimates but transitory fluxes due to changes involving new forest planting or continuous emissions due to drainage of organic soils for agriculture are discussed elsewhere.

2.2.11.(c) ii - Liming of Agricultural Soils

Emissions due to liming of agricultural soils were following a downward trend that started in 1997 but in 2003 there has been a rise. The peak emission was 1515 Gg in 1996 but in 2001 this has fallen to 752 Gg but by 2003 had risen to 918 Gg. No information is presently available to explain this trend but it may be related to varying economic conditions in farming.

2.2.11.(c) iii - Forest Soils

All changes in stock of carbon in forest soils are now estimated to be significantly greater than previously reported due to the inclusion of accumulating carbon in soils of conifer forest (see Section 2.2.4. Forest soil carbon stocks are now estimated to have increased due to a sink of 5610 Gg for 2003. Removals of atmospheric carbon dioxide to the soils of the new forests have not varied much over the period 1990 to 2003 but show a peak of 6633 Gg in 1998 followed by a slow downward trend. These trends reflect variation in planting rates in the past now working through the slowly responding soil turnover system.

2.2.11.(c) iv - Lowland (fen) peat drainage

The downward trend in Emissions from drainage of organic soils in the lowlands (primarily English fens) continues for 2003. The Emissions are estimated to have fallen from 1650 Gg in 1990 to 1217 Gg in 2003 reflecting stabilisation of in the old drained areas.

2.2.11.(d) Other

2.2.11.(d) i - Changes in Non-forest Biomass

The uptake of carbon due to improvements in the productivity and area of crops is estimated in 2003 to be unchanged from previous years at 1100 Gg.

2.2.11.(d) ii - Peat Extraction

The estimated emission of carbon due to peat extraction shows variation both upwards and downwards over the 14 reported years with the latest year of 2003 showing an emission of 894 Gg compared to the lowest in the previous 11 years of 704 Gg estimated for 1998. Emissions were greatest at 950 Gg in 1995 and around 800 Gg in the early part of the decade

2.2.11.(e) Net UK Emissions/Removals

The picture of net emissions in the UK from the Land Use Change and Forestry Sector of the UK has changed significantly due to the data revisions introduced this year. For 1990 the UK remains a net emitter but the value of the emission is now estimated to be 2645 Gg CO_2 made up of 17558 Gg emissions offset by 14913 Gg of removals. With the revised data Scotland is shown to be a net remover of atmospheric CO_2 in 1990 because of the combination of enhanced estimated removals to the soil of the extensive conifer forest and reduced estimated losses from the soils of other land. England and N. Ireland are estimated to be net emitters in 1990 and Wales a net remover. The net emissions for the UK followed a downward trend, reaching zero between 1997 and 1998 continuing to a net removal of 1536 Gg in 2003. This downward trend is similar but a little less steep than reported in previous inventories.

2.3. LULUCF GHG Data on basis of IPCC 2004 Good Practice Guidance.

2.3.1. Introduction

In the recently produced (IPCC 2004) IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry a uniform structure to reporting emissions and removals of green house gases was described. This was adopted by the UNFCCC at COP 10 and countries were asked to submit data in this format in 2005. The timescales were short for adapting existing methodologies and data for the UK, especially as extensive revisions to these were to be carried out separately from any reporting requirements. Finally the approach was taken to submit Common Reporting Format Tables for LULUCF in both the previous format and the new format.

The new format for reporting can be seen as “land based” with the need for all land in the country to be identified as having remained in one of 6 classes (Forest Land, Cropland, Grassland, Wetlands, Settlements, Other land) since a previous survey, or as having changed to a different (identified) class in that period. A land use change matrix can be used to capture all these transitions in a compact manner. At its most basic this would be a 6x6 matrix with the diagonal being the areas that remained unchanged and the off-diagonal entries being the areas that had changed. The reporting structure simplifies this 6x6 structure to a 6x2 structure where the 2 columns describe greenhouse gas fluxes associated with i) land that remained in a specific class or ii) converted into that class. For each of these 6x2 reporting groups changes in stocks of carbon for above ground biomass, below ground biomass, dead biomass and soil organic matter should be reported, where possible. Specific activities that do not directly cause stock change of carbon are reported in separate tables, e.g. greenhouse gases other than CO_2, but are combined into the totals in a summary table for the Sector. In the UK we do not have a fully integrated methodology to match the new reporting structure but because of our work using land use change matrices for estimating the effect of land use change on soil carbon stock it has been a relatively easy step to match the calculations that are made with those needed in the 6x2 reporting structure. Further work is planned to align methodologies with this structure.

The LULUCF GPG allows modification of the basic set of six land classes to match national databases. Further subdivision of the classes by ecosystem, administrative region or time of occurrence of change is also encouraged.

Deforestation is not directly treated within this structure but may contribute to 5 “conversion to” categories depending on the final use of the previous forest. The total stock change for deforestation must be identified form the reported data and entered as separate “For Information” results.

The full detail of disaggregation of results reported to the UNFCCC is not provided here but will be made available at http://www.edinburgh.ceh.ac.uk/ukcarbon.

2.3.2. Forest Land (5A)

2.3.2.(a) Forest Land remaining Forest Land

Changes in stock of carbon in Forest Land in the UK that remains Forest Land are assumed to be zero. This category is identified with 820,000 ha of forest that has existed since before 1920 and is also assumed to be in carbon balance because of its age and hence has zero stock change.

2.3.2.(b) Land converting to Forest Land

All afforestation occurring since 1920 is reported in this category. This data was reported under Category 5A or 5A/5D in previous reporting formats. Stock changes in above and below ground biomass, dead material (litter) and soil carbon are estimated by the C-Flow model as described in Section 2.2.1. The data was reported to UNFCCC further disaggregated by the time periods for planting of 1920-1949, 1950-1979 and 1080 – 2003 to align with periods used for Cropland and Grassland. The data was also reported disaggregated by afforestation in England, Scotland, Wales and N. Ireland. The effect of afforestation in period 1990 –2003 was not reported separately but was calculated for use in assessing possible removals under Article 3.3 of the Kyoto Protocol.

2.3.3. Cropland

2.3.3.(a) Cropland remaining Cropland

Ongoing emissions of CO_2 due to historical drainage of lowland fens (Section 2.2.6) are reported in this Category. This data was reported in Category 5D or 5E in previous formats.

Emissions of CO_2 due to liming of cropland are reported in this Category. This data was combined with fluxes from agricultural grassland and reported in Category 5D of previous formats.

2.3.3.(b) Land converting to Cropland

Changes in stocks of soil carbon due to land converting to Cropland from all other land types as described by the land use change matrices of the Monitoring Landscape Change and Countryside Surveys (see Section 2.2.3) are reported in this Category. The data are disaggregated by changes occurring between 1950 –1979 and 1980-2003 as well as by England, Scotland, Wales and N. Ireland. Changes in stocks of biomass are not reported here but are dealt with under “changes in stock of non-forest biomass” but further work is required.

2.3.4. Grassland (5C)

2.3.4.(a) Grassland remaining Grassland

Ongoing emissions of CO_2 due to peat extraction (Section 2.2.8) are reported in this Category. This data was reported in Category 5E in previous formats.

Emissions of CO_2 due to liming of grassland are reported in this Category (Section 2.2.5). This data was combined with fluxes from cropland and reported in Category 5D of previous formats.

2.3.4.(b) Land converting to Grassland

Changes in stocks of soil carbon due to land converting to Grassland from all other land types as described by the land use change matrices of the Monitoring Landscape Change and Countryside Surveys (see Section 2.2.3) are reported in this Category. The data are disaggregated by changes occurring between 1950 –1979 and 1980-2003 as well as by England, Scotland, Wales and N. Ireland. Changes in stocks of biomass are not reported here but are dealt with under “changes in stock of non-forest biomass” but further work is required.

2.3.5. Wetlands (5D)

In the UK Wetlands will either be saturated land (e.g. bogs, marshes) and due to the classifications used in the CS will fall into the Grassland category or open water (e.g. lakes, rivers, reservoirs) and included in the Other Land category

2.3.6. Settlements (5E)

2.3.6.(a) Settlements remaining Settlements

No changes in carbon stocks are reported for land remaining under settlement. A possible cause of carbon stock change with time would be increasing or decreasing stock of biomass in parks or gardens. This conceptually dealt with under the "changes in stock of non-forest biomass" but further work is required

2.3.6.(b) Land converting to Settlements

Changes in stocks of soil carbon due to land converting to Settlement from all other land types as described by the land use change matrices of the Monitoring landscape Change and Countryside Surveys (see Section 2.2.3) are reported in this Category. The data are disaggregated by changes occurring between 1950 –1979 and 1980-2003 as well as by England, Scotland, Wales and N. Ireland. Some changes in stocks of biomass are not reported here but are dealt with under "changes in stock of non-forest biomass" but further work is required. However it is assumed that most deforestation occurs due to expansion of villages and towns so loss of forest biomass stock and emissions of non-CO_2 gases due to burning of litter material are reported in this category. The changes in stocks of soil carbon due to deforestation will also be relevant to this category but are not specifically identified separately with such changes in other land types becoming settled. A separate assessment of the changes in soil carbon stocks was made and reported with the biomass loss etc. in the appropriate Information Item.

2.3.7. Other Land (5F)

No emissions or removals are reported in this category. It is assumed that there are very few areas of land of other types become bare rock or water bodies, which make up the majority of this type. Further assessment of areas of new reservoirs or coastal flooding may be worth pursuing.

2.3.8. Other Activities (5G)

Changes in stocks of carbon in harvested wood (Section 2.2.1 products are reported here. This data was reported in Category 5A in previous formats. It was not possible to disaggregate the data on changes in stocks of carbon in non-forest biomass discussed in Section 2.2.7 into contributions due to changes in Cropland, Grassland and Settlements. They were therefore reported under the Other Category 5G of the new reporting format.

2.4. Projections of Emissions and Removals to 2020

2.4.1. Introduction

Projections of emissions for years from 2004 to 2020 have been made for each activity for each of England, Scotland, Wales and Northern Ireland. A "central" (MID), high emission (HI) and low emission scenario (LO) was developed for each activity and the basis of these is described in Section 2.4.2. The UK emissions, removals and net flux for each scenario are presented in Table 2-32. More detailed information on the emissions and removals is only supplied for simplicity on the basis of the reporting format defined by the IPCC LULUCF Good Practice Guidance (Appendix 1).

2.4.2. Basis for projections

The basis for projection of each activity varied between England, Scotland, Wales and N. Ireland as appropriate. These assumptions are described in Table 2-28, Table 2-29, Table 2-30 and Table 2-31 respectively.

2.4.3. Results for projections of LUCF Categories

The projections for Mid, Low and High emissions scenarios for the UK, England, Scotland, Wales and N. Ireland are presented in the Tables of Appendix A.1. The UK emissions, removals and net flux for each scenario are presented in Table 2-32 and plotted in Figure 2-1. The reporting format of the GPG on LULUCF is used for these data. Projections to 2020 of Forest Land, Cropland, Grassland and Settlements (Urban) Emissions and Removals of carbon from atmosphere in United Kingdom are plotted in Figure 2-2. Projections to 2020 of Net Emissions and Removals of carbon from atmosphere in England, Scotland, Wales and N. Ireland are plotted in Figure 2-3. Projections of net fluxes for Forest Land, Cropland, Grassland and Settlements for each scenario for England, Scotland, Wales and N. Ireland are plotted in Figure 2-4, Figure 2-5, Figure 2-6 and Figure 2-7.

2.4.4. Kyoto Protocol Article 3.3: Removals and emissions associated with post-1990 afforestation and deforestation

Projections of emissions associated with afforestation and deforestation since 1990 as required by the Kyoto Protocol Article 3.3 have been made. The scenarios used for the projections described above formed the basis for these post 1990 calculations. For changes in biomass and soil carbon stocks due to afforestation the C-Flow model was used but with planting data restricted to the post-1990 period. Biomass carbon stock changes and non-CO_2 emissions from burning occur immediately in the year of forest clearance therefore this contribution is equal to that reported for the annual UNFCCC Inventory. However a separate calculation of the changes in soil carbon stock due to post-1990 deforestation specifically was made.

These projections are presented for Mid, Low and High emissions scenarios for the UK, England, Scotland, Wales and N. Ireland in Appendix A.4.

2.4.5. Kyoto Protocol Article 3.4: Removals and emissions associated Cropland Management and Grassland Management

Under Article 3.4 of the Kyoto Protocol countries may elect to use net sinks within Cropland Management (CM) and Grassland Management (GM) to offset emissions in the commitment period. According to the IPCC LULUCF Good Practice Guidance emissions and removals for CM should consider land that has remained as cropland, land that has become cropland and land that changes out of cropland between two survey dates. For GM calculations land should be considered that has remained as grassland, land that has become grassland and land that changes out of grassland between two survey dates. Afforestation and deforestation should be dealt with prior to treating CM and GM. The period between surveys is suggested as twenty years as a default to allow soil carbon changes to equilibrate but it is recognized that in individual countries better information may be available. In the UK we treat changes of soil carbon stocks as described in Section 2.2.3 where the time to equilibrate is different for different land transitions but the principle of having emissions/removals due to transitions between different land types is inherent. It can be shown (Box 1) that for the UK net flux for CM plus GM can be calculated from data in the categories of the LULUCF GPG reporting format as the algebraic sum (5B Cropland) + (5C Grassland) + (5E Settlements) – (Deforestation). Fluxes calculated in this way for years 1990 to 2020 assuming different future emissions scenarios are shown in Table 2-27.

Table 2-27 Net fluxes for Cropland Management plus Grassland Management in the UK for consideration in context of Kyoto protocol Article 3.4 for three different future emissions scenarios. (Italics are projections)

Gg CO2/year	**Art 3.4 CM + GM Low scenario**	**Art 3.4 CM + GM Mid scenario**	**Art 3.4 CM + GM High scenario**
1990	**16816**	**16816**	**16816**
1991	16952	16952	16952
1992	16771	16771	16771
1993	15881	15881	15881
1994	15936	15936	15936
1995	**16072**	**16072**	**16072**
1996	15798	15798	15798
1997	15402	15402	15402
1998	14836	14836	14836
1999	14621	14621	14621
2000	**14367**	**14367**	**14367**
2001	14199	14199	14199
2002	13910	13910	13910
2003	14172	14172	14172
2004	*13728*	*13952*	*14155*
2005	***13119***	***13549***	***13957***
2006	*12471*	*13106*	*13717*
2007	*12198*	*13033*	*13848*
2008	*11855*	*12887*	*13905*
2009	*11582*	*12809*	*14014*
2010	***10778***	***12649***	***14184***
2011	*10237*	*12513*	*14314*
2012	*10002*	*12381*	*14423*
2013	*9818*	*12170*	*14372*
2014	*9680*	*12093*	*14357*
2015	***9484***	***11942***	***14367***
2016	*9371*	*11919*	*14522*
2017	*9151*	*11740*	*14443*
2018	*9059*	*11680*	*14424*
2019	*8938*	*11614*	*14417*
2020	***8813***	***11656***	***14552***

There are 4 land types relevant to greenhouse gas emissions and removals in the UK: Forest (F), Cropland (C), Grassland (G) and Settlements (S). Using the 2 letter combinations of land type at start of a survey period followed by the land type at end e.g. FF is forest remaining forest, CG is cropland converting to grassland, it is possible to write (algebraic sums)

Art 3.4 Cropland Management (CM) = CC + GC + SC +CG +CS

Art 3.4 Grassland Management (GM) = GG + CG + SG + GC + GS

Inventory Cropland (IC) = CC + GC + SC + FC

Inventory Grassland (IG) = GG + CG + SG + FG

Inventory Settlements (IS) = SS + CS + GS + FS

SS = 0

Therefore CM + GM = IC + IG + IS – (FC + FG +FS)

= IC + IG + IS – (Deforestation)

Box 1 Estimation of Article 3.4 emissions for Cropland Management and Grassland Management from GHG Inventory data.

2.4.6. Kyoto Protocol Article 3.7: Deforestation emissions in Base Year

Under Kyoto protocol Article 3.7 countries with a net emissions in 1990 from the LULUCF Sector can count that part of these emissions due to deforestation with non-LULUCF GHG emissions for estimating “Base Year Emission”. These “Base Year Emissions” then become the basis for the emissions allowance for that country during the First Commitment Period. In 1990 the UK LULUCF Sector is estimated to have been a net emitter of 2645 Gg CO_2, so Article 3.7 therefore applies. The deforestation emission in 1990 for the purposes of this Article have been taken to be those associated with all deforestation prior to including 1990. For 1990 the immediate emissions due to biomass removal and burning are relevant but there will also be delayed soil carbon stock change resulting from deforestation in earlier years. The emissions to be used for Article 3.7 are therefore the full 1990 deforestation component for 1990 from the GHG Inventory, which equals 759 Gg CO_2.

Table 2-28 Assumptions in scenarios for projection of LUCF Emissions and Removals from 1990 to 2003 data to 2004 onwards

a	**Scenario assumption: Scotland**		
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Afforestation	UK Total of 30 kha/yr from 2003 in proportion to 2003 planting	All planting from 2004 assumed to follow policy based on projected Woodland Grant Scheme support.	All planting from 2004 assumed to be 0 ha/yr.
Deforestation	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Land Use Change (Soils)	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – minimum values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – mean values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – maximum values from Monte Carlo simulation
Peat extraction	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 Scottish data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Liming	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Lowland drainage	NA	NA	NA
Non-forest biomass	Flux remains at 2002 value	Flux remains at 2002 value	Flux remains at 2002 value

Table 2-29 Assumptions in scenarios for projection of LUCF Emissions and Removals from 1990 to 2003 data to 2004 onwards

b	**Scenario assumption: England**		
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Forestry	UK Total of 30 kha/yr from 2004 in proportion to 2003 planting	Conifer planting from 2003 assumed to be 500 ha/year Broadleaf planting from 2003 assumed to be 4500 ha/year	Conifer planting from 2004 assumed to be 0 ha/yr. Broadleaf planting from 2004 assumed to be 0 ha/yr.
Deforestation	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Land Use Change (Soils)	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – minimum values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – mean values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – maximum values from Monte Carlo simulation
Peat extraction	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 English data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Liming	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Lowland drainage	Flux changes from 2003 at modelled rate of change for 1990 to 2000	Flux changes from 2003 at modelled rate of change	Flux changes from 2003 value at modelled rate of change for 2010 to 2020
Non-forest biomass	Flux remains at 2003 value	Flux remains at 2003 value	Flux remains at 2003 value

Table 2-30 Assumptions in scenarios for projection of LUCF Emissions and Removals from 1990 to 2003 data to 2004 onwards

c	Scenario assumption: Wales		
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Forestry	UK Total of 30 kha/yr from 2004 in proportion to 2003 planting	Conifer planting from 2004 assumed to be as in 2003. Broadleaf planting from 2004 assumed to be as in 2003.	Conifer planting from 2004 assumed to be 0 ha/yr. Broadleaf planting from 2004 assumed to be 0 ha/yr.
Deforestation	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Land Use Change (Soils)	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – minimum values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – mean values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – maximum values from Monte Carlo simulation
Peat extraction	Flux zero	Flux zero	Flux zero
Liming	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Lowland drainage	NA	NA	NA
Non-forest biomass	Flux remains at 2003 value	Flux remains at 2003 value	Flux remains at 2003 value

Table 2-31 Assumptions in scenarios for projection of LUCF Emissions and Removals from 1990 to 2002 data to 2003 onwards

d	Scenario assumption: Northern Ireland		
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Forestry	UK Total of 30 kha/yr from 2004 in proportion to 2003 planting	Conifer planting from 2004 assumed to be as in 2003. Broadleaf planting from 2004 assumed to be as in 2003.	Conifer planting from 2004 assumed to be 0 ha/yr. Broadleaf planting from 2004 assumed to be 0 ha/yr.
Deforestation	NA	NA	NA
Land Use Change (Soils)	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – minimum values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – mean values from Monte Carlo simulation	Annual area land use change for 2004 to 2020 assumed to be same as annual rate of change for 1990 to 2003. – maximum values from Monte Carlo simulation
Peat extraction	Flux remains at 2003 value	Flux remains at 2003 value	Flux remains at 2003 value
Liming	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2003 trend	Autoregressive model (10 terms) fitted to 1990 to 2003 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2003 trend
Lowland drainage	NA	NA	NA
Non-forest biomass	Flux remains at 2003 value	Flux remains at 2003 value	Flux remains at 2003 value

Table 2-32 Inventory (1990 to 2000) and projected (2005 to 2020) Emissions and Removals data ($GgCO_2$/year). (-ve sign indicates Removal)

Year	Net (LOW)	*Emissions (MID)*	**Net (MID)**	*Removals (MID)*	Net (HIGH)
1990	2645	*17558*	**2645**	*-14913*	2645
1995	787	*16737*	**787**	*-15950*	787
2000	-787	*15038*	**-787**	*-15826*	-787
2005	-2939	*14136*	**-2442**	*-16578*	-1968
2010	-4466	*13236*	**-2124**	*-15360*	-270
2015	-4625	*12497*	**-463**	*-12960*	3065
2020	-4208	*12156*	**1351**	*-10805*	5993

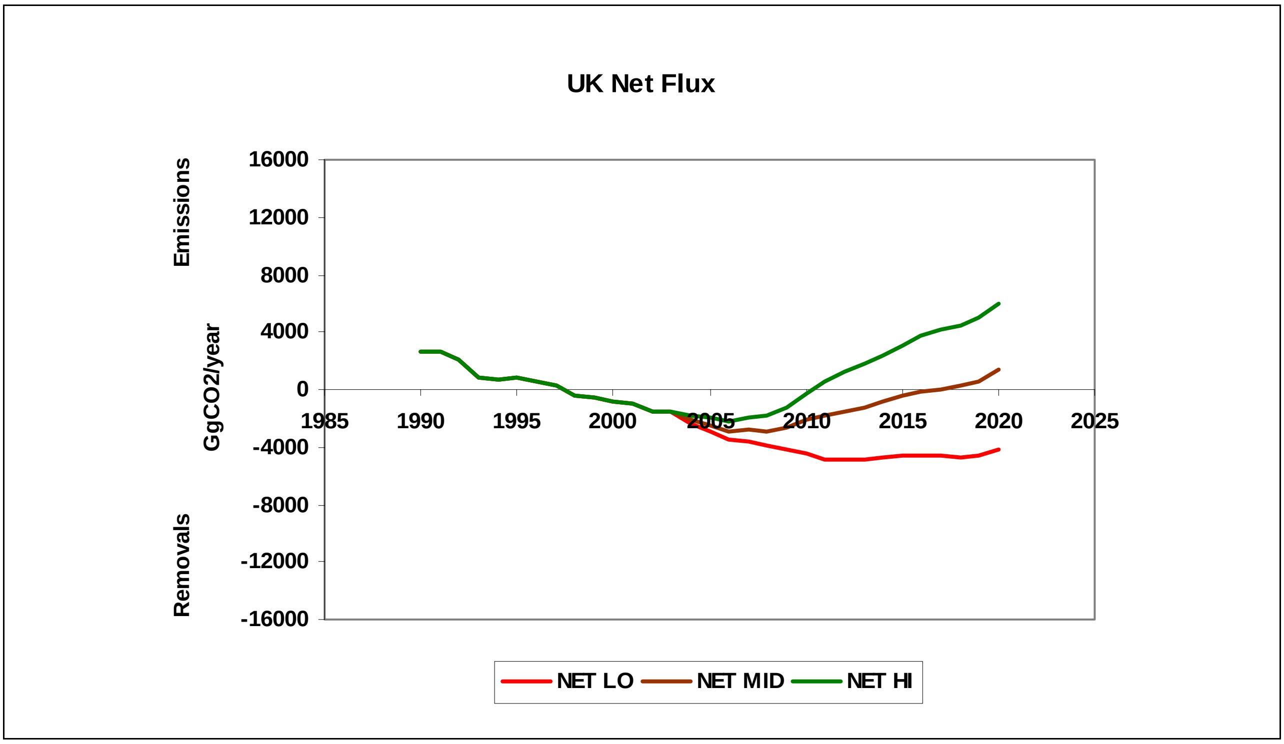

Figure 2-1 Projections to 2020 of Net Emissions and Removals of carbon from atmosphere in United Kingdom by land use, land use change and forestry for 3 future emissions scenarios

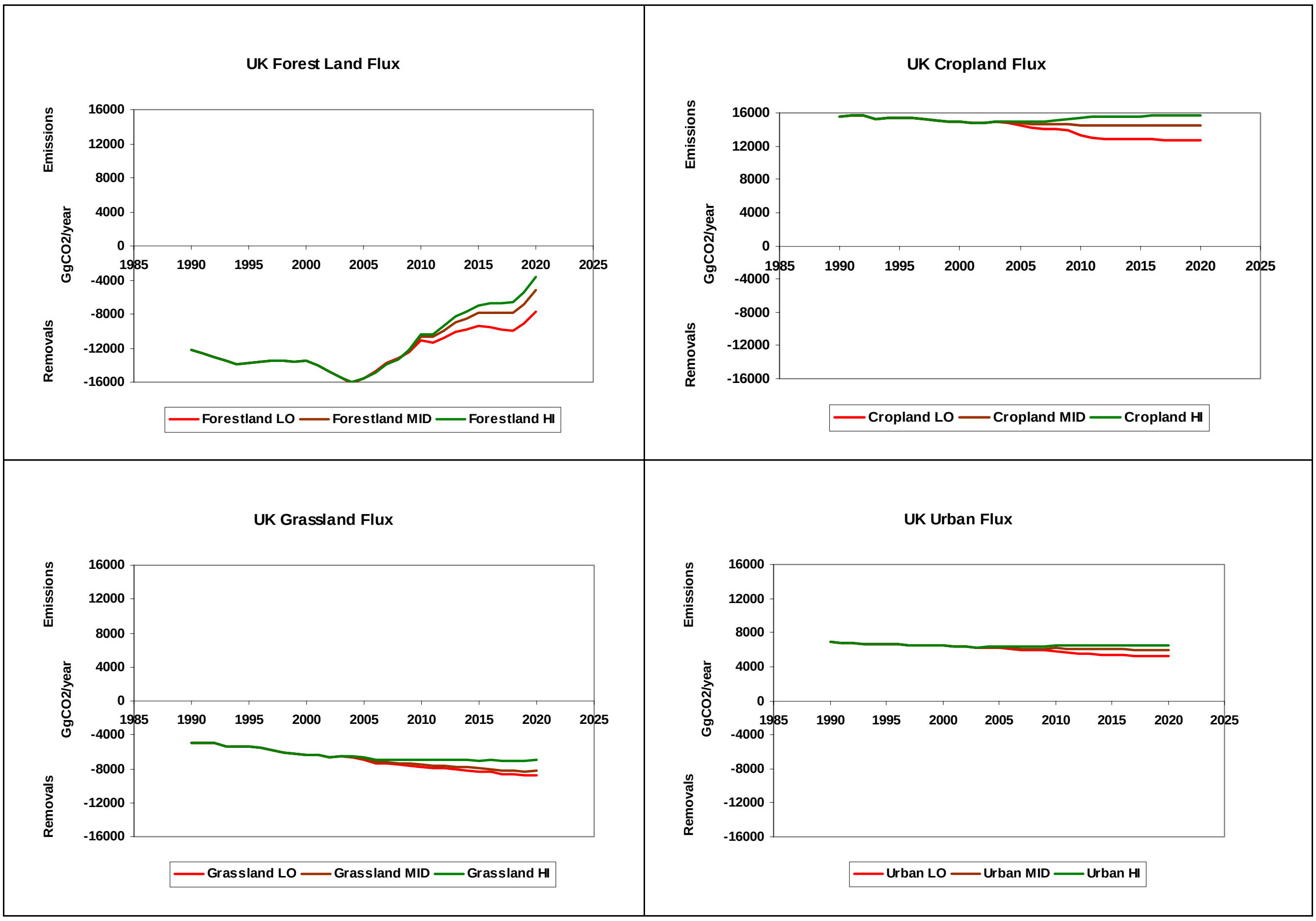

Figure 2-2 Projections to 2020 of Forest Land, Cropland, Grassland and Settlements (Urban) Emissions and Removals of carbon from atmosphere in United Kingdom by land use, land use change and forestry for 3 future emissions scenarios

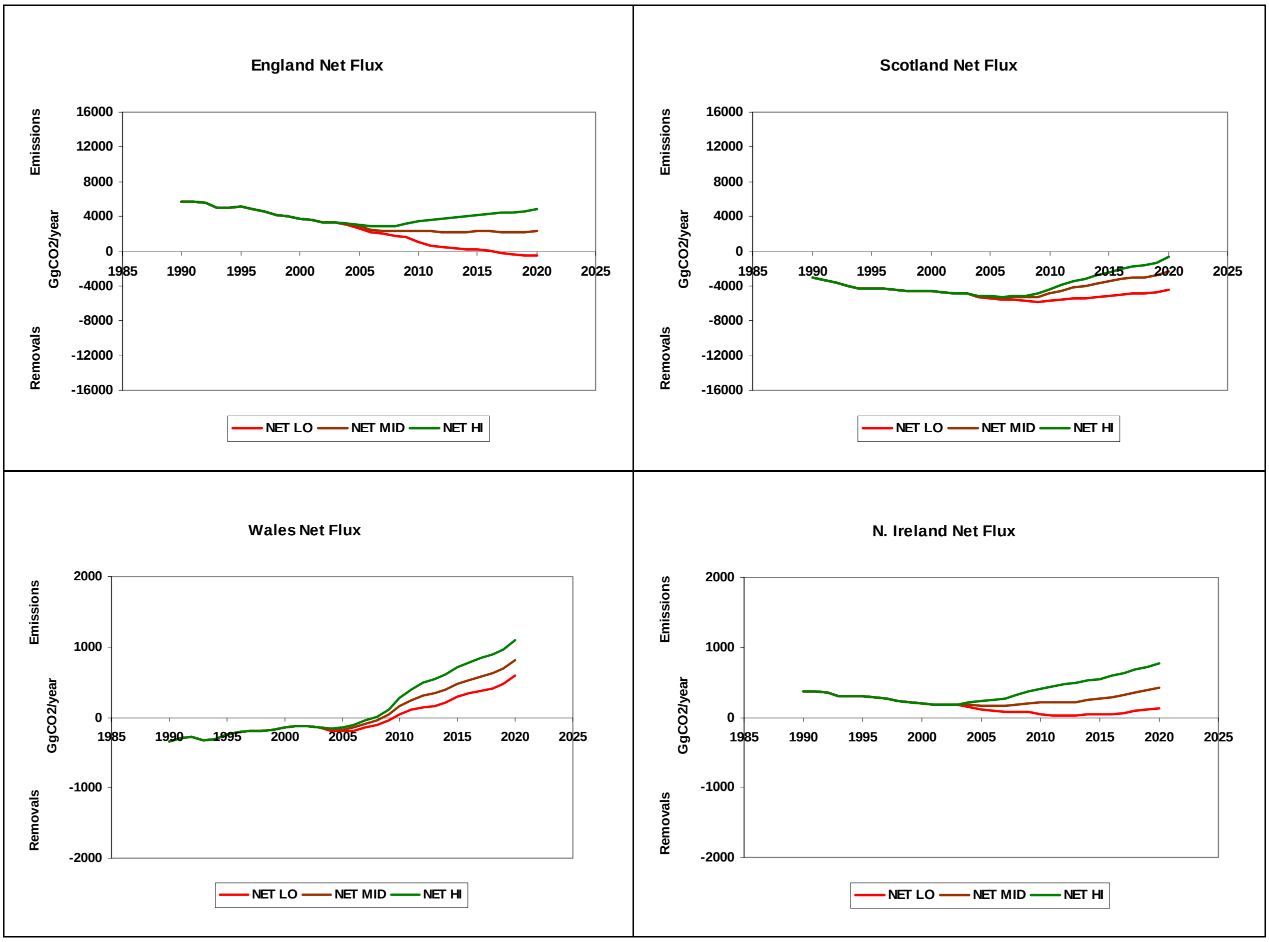

Figure 2-3 Projections to 2020 of Net Emissions and Removals of carbon from atmosphere in England, Scotland, Wales and N. Ireland by land use, land use change and forestry for 3 future emissions scenarios.

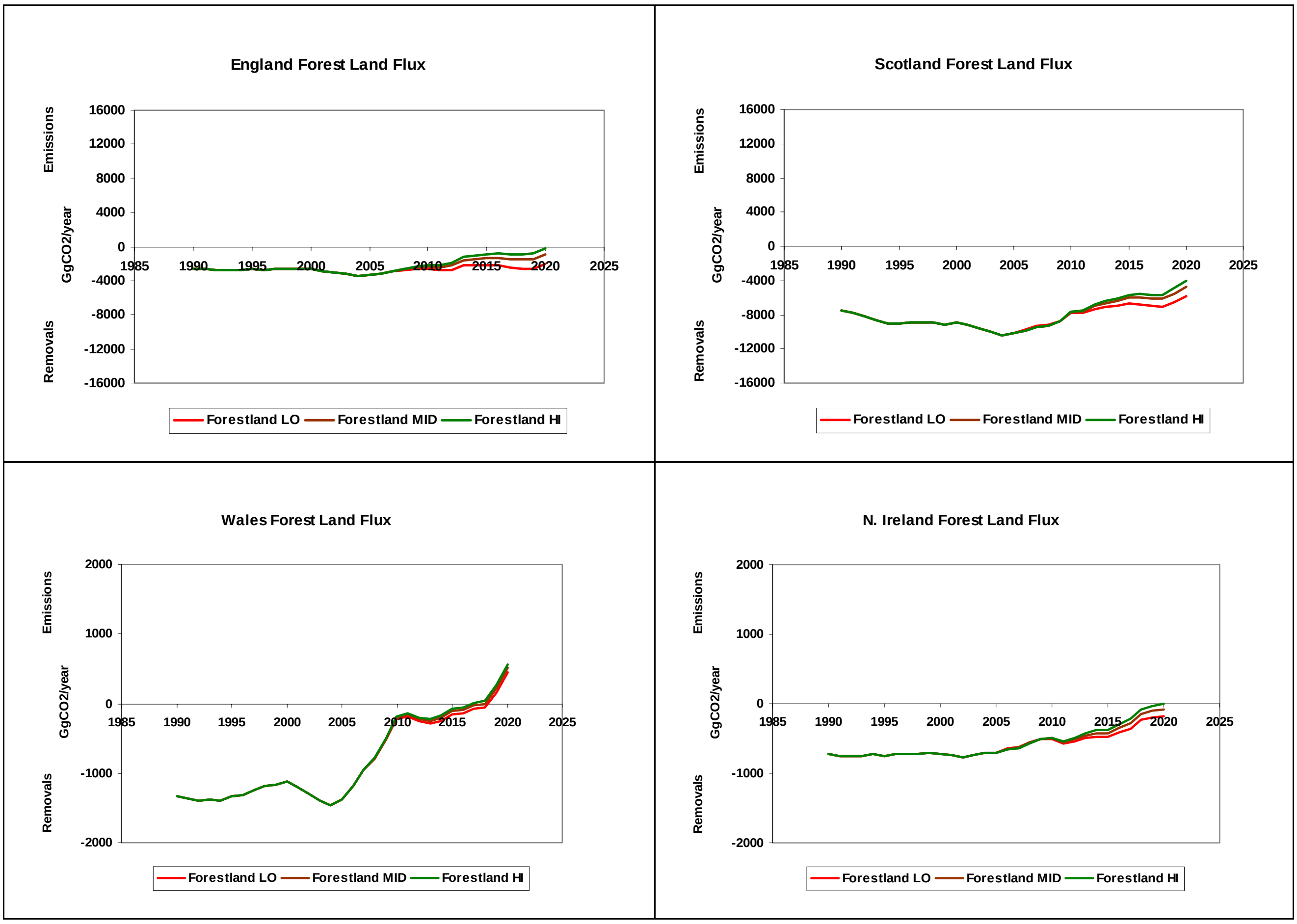

Figure 2-4 Projections to 2020 of Emissions and Removals of carbon from atmosphere in England, Scotland, Wales and N. Ireland by Forest Land Category of land use, land use change and forestry sector for 3 future emissions scenarios.

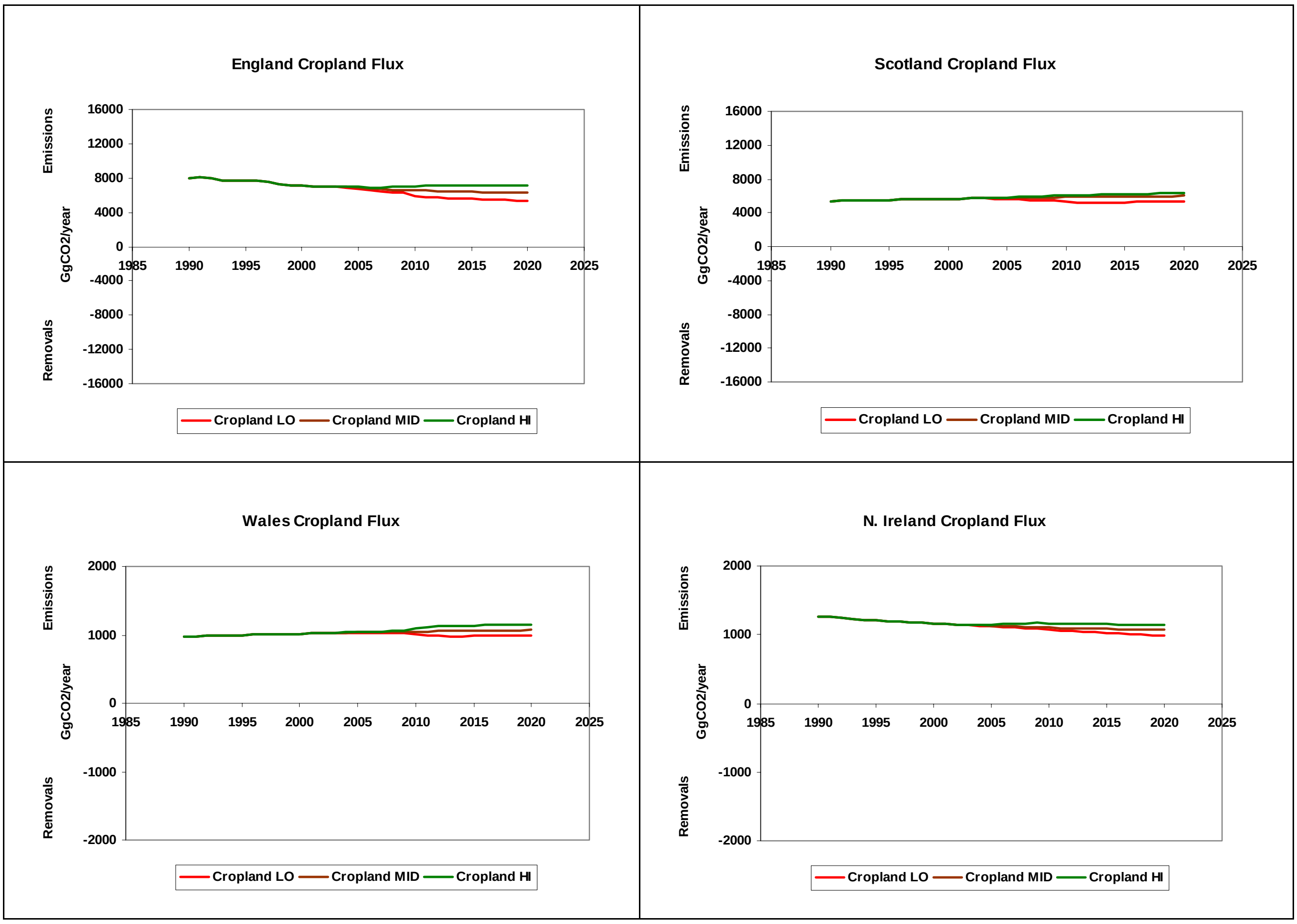

Figure 2-5 Projections to 2020 of Emissions and Removals of carbon from atmosphere in England, Scotland, Wales and N. Ireland by Cropland Category of land use, land use change and forestry sector for 3 future emissions scenarios

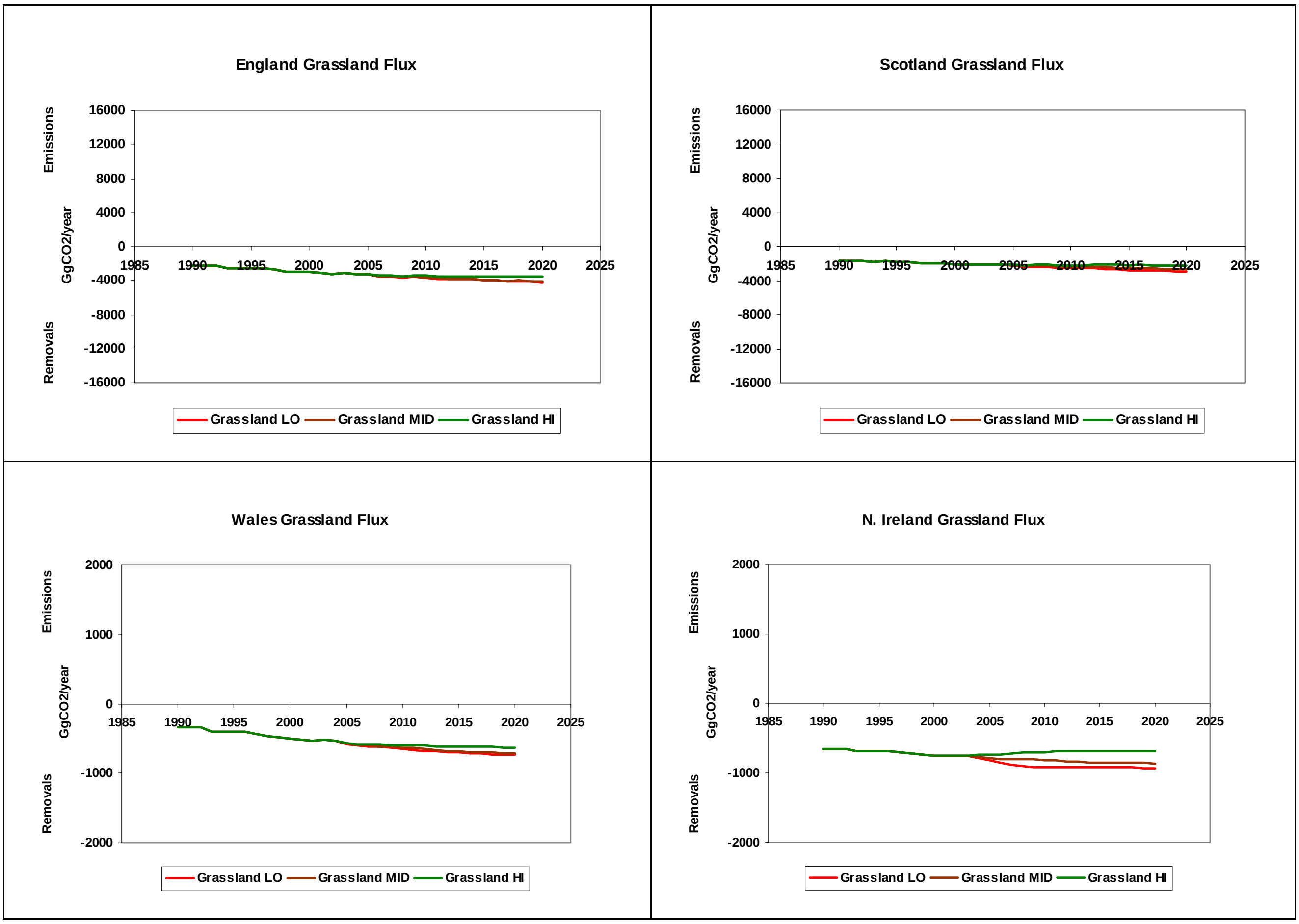

Figure 2-6 Projections to 2020 of Emissions and Removals of carbon from atmosphere in England, Scotland, Wales and N. Ireland by Grassland Category of land use, land use change and forestry sector for 3 future emissions scenarios

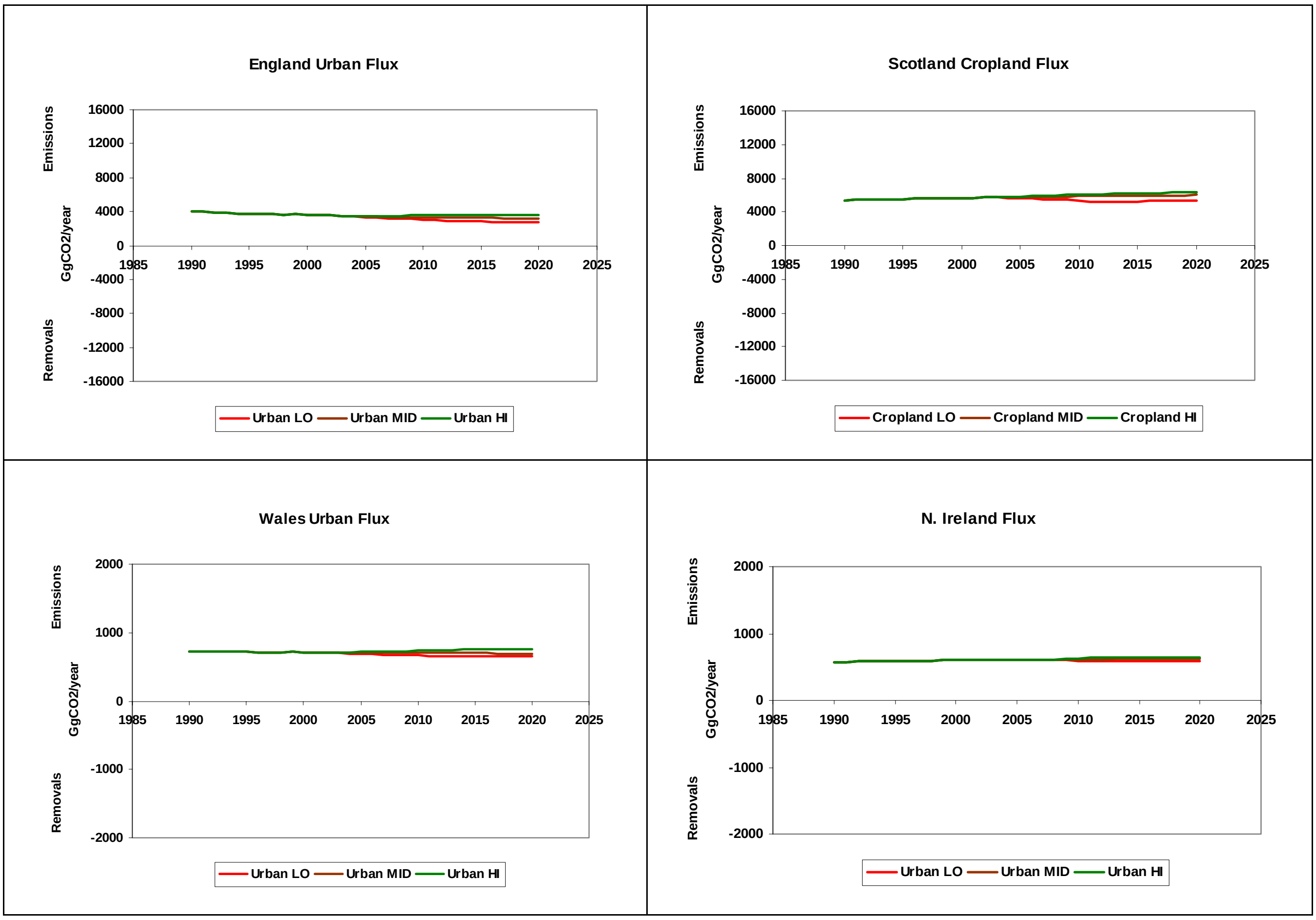

Figure 2-7 Projections to 2020 of Emissions and Removals of carbon from atmosphere in England, Scotland, Wales and N. Ireland by Settlements (Urban) Category of land use, land use change and forestry sector for 3 future emissions scenarios

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APPENDIX 1

A.1. Data Tables

Table A1. 1: United Kingdom data for 2003 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection, D: "NIR" summary, of Inventory period (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) UK **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**2645**	**-12226**	**15544**	**-4929**	**6944**	**-1587**	**-1100**
1991	2590	-12616	15693	-4886	6844	-1344	-1100
1992	2076	-13118	15681	-5003	6746	-1130	-1100
1993	899	-13478	15286	-5450	6699	-1059	-1100
1994	685	-13858	15331	-5394	6647	-942	-1100
1995	**787**	**-13727**	**15442**	**-5326**	**6621**	**-1123**	**-1100**
1996	616	-13661	15407	-5525	6593	-1098	-1100
1997	211	-13527	15289	-5766	6511	-1195	-1100
1998	-385	-13459	15108	-6117	6473	-1289	-1100
1999	-550	-13665	14990	-6182	6568	-1161	-1100
2000	**-787**	**-13411**	**14917**	**-6333**	**6455**	**-1314**	**-1100**
2001	-986	-14009	14870	-6426	6422	-743	-1100
2002	-1489	-14775	14869	-6688	6339	-133	-1100
2003	-1536	-15418	14956	-6489	6268	248	-1100
2004	*-2088*	*-16067*	*14902*	*-6632*	*6265*	*544*	*-1100*
2005	***-2442***	***-15561***	***14730***	***-6842***	***6248***	***83***	***-1100***
2006	*-2888*	*-14865*	*14626*	*-7161*	*6172*	*-560*	*-1100*
2007	*-2823*	*-13864*	*14601*	*-7190*	*6148*	*-1417*	*-1100*
2008	*-2874*	*-13263*	*14611*	*-7329*	*6120*	*-1912*	*-1100*
2009	*-2670*	*-12283*	*14595*	*-7374*	*6148*	*-2655*	*-1100*
2010	***-2124***	***-10662***	***14554***	***-7479***	***6160***	***-3598***	***-1100***
2011	*-1795*	*-10729*	*14536*	*-7583*	*6142*	*-3062*	*-1100*
2012	*-1469*	*-9983*	*14501*	*-7667*	*6103*	*-3323*	*-1100*
2013	*-1248*	*-8991*	*14428*	*-7792*	*6080*	*-3873*	*-1100*
2014	*-889*	*-8553*	*14424*	*-7853*	*6072*	*-3879*	*-1100*
2015	***-463***	***-7923***	***14429***	***-7999***	***6067***	***-3937***	***-1100***
2016	*-88*	*-7818*	*14433*	*-8016*	*6027*	*-3614*	*-1100*
2017	*63*	*-7905*	*14438*	*-8190*	*5986*	*-3165*	*-1100*
2018	*246*	*-7837*	*14442*	*-8246*	*5955*	*-2968*	*-1100*
2019	*577*	*-6858*	*14446*	*-8308*	*5956*	*-3560*	*-1100*
2020	***1351***	***-5160***	***14450***	***-8262***	***5968***	***-4545***	***-1100***

B (Low) UK Gg CO2/year	5 NET	5A Forestland	5B Cropland	5C Grassland	5E Settlements	5G HWP	5G Non-forest biomass
1990	**2645**	**-12226**	**15543**	**-4929**	**6944**	**-1587**	**-1100**
1991	2590	-12616	15693	-4886	6844	-1344	-1100
1992	2076	-13118	15681	-5003	6746	-1130	-1100
1993	899	-13478	15286	-5449	6699	-1059	-1100
1994	685	-13858	15331	-5393	6647	-942	-1100
1995	**787**	**-13727**	**15442**	**-5326**	**6621**	**-1123**	**-1100**
1996	616	-13661	15406	-5525	6593	-1098	-1100
1997	211	-13527	15289	-5766	6511	-1195	-1100
1998	-385	-13459	15108	-6117	6473	-1289	-1100
1999	-550	-13665	14990	-6182	6568	-1161	-1100
2000	**-787**	**-13411**	**14916**	**-6332**	**6455**	**-1314**	**-1100**
2001	-986	-14009	14870	-6426	6422	-743	-1100
2002	-1489	-14775	14869	-6688	6339	-133	-1100
2003	-1536	-15418	14956	-6489	6268	248	-1100
2004	*-2397*	*-16142*	*14766*	*-6687*	*6221*	*544*	*-1100*
2005	***-2939***	***-15607***	***14471***	***-6944***	***6159***	***83***	***-1100***
2006	*-3492*	*-14804*	*14243*	*-7309*	*6038*	*-560*	*-1100*
2007	*-3613*	*-13779*	*14098*	*-7386*	*5971*	*-1417*	*-1100*
2008	*-3945*	*-13251*	*13989*	*-7571*	*5900*	*-1912*	*-1100*
2009	*-4108*	*-12433*	*13857*	*-7662*	*5885*	*-2655*	*-1100*
2010	***-4466***	***-11037***	***13311***	***-7798***	***5756***	***-3598***	***-1100***
2011	*-4819*	*-11355*	*12998*	*-7915*	*5615*	*-3062*	*-1100*
2012	*-4857*	*-10859*	*12897*	*-7998*	*5527*	*-3323*	*-1100*
2013	*-4855*	*-10105*	*12844*	*-8089*	*5467*	*-3873*	*-1100*
2014	*-4789*	*-9888*	*12829*	*-8178*	*5427*	*-3879*	*-1100*
2015	***-4625***	***-9467***	***12810***	***-8336***	***5405***	***-3937***	***-1100***
2016	*-4548*	*-9562*	*12787*	*-8414*	*5355*	*-3614*	*-1100*
2017	*-4641*	*-9843*	*12761*	*-8596*	*5302*	*-3165*	*-1100*
2018	*-4689*	*-9965*	*12732*	*-8647*	*5258*	*-2968*	*-1100*
2019	*-4614*	*-9176*	*12705*	*-8727*	*5246*	*-3560*	*-1100*
2020	***-4208***	***-7672***	***12678***	***-8812***	***5242***	***-4545***	***-1100***

C (High) UK **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**2645**	**-12226**	**15543**	**-4929**	**6944**	**-1587**	**-1100**
1991	2590	-12616	15693	-4886	6844	-1344	-1100
1992	2076	-13118	15681	-5003	6746	-1130	-1100
1993	899	-13478	15286	-5449	6699	-1059	-1100
1994	685	-13858	15331	-5393	6647	-942	-1100
1995	**787**	**-13727**	**15442**	**-5326**	**6621**	**-1123**	**-1100**
1996	616	-13661	15406	-5525	6593	-1098	-1100
1997	211	-13527	15289	-5766	6511	-1195	-1100
1998	-385	-13459	15108	-6117	6473	-1289	-1100
1999	-550	-13665	14990	-6182	6568	-1161	-1100
2000	**-787**	**-13411**	**14916**	**-6332**	**6455**	**-1314**	**-1100**
2001	-986	-14009	14870	-6426	6422	-743	-1100
2002	-1489	-14775	14869	-6688	6339	-133	-1100
2003	-1536	-15418	14956	-6489	6268	248	-1100
2004	*-1823*	*-16020*	*15002*	*-6561*	*6311*	*544*	*-1100*
2005	***-1986***	***-15543***	***14932***	***-6699***	***6341***	***83***	***-1100***
2006	*-2285*	*-14917*	*14929*	*-6946*	*6309*	*-560*	*-1100*
2007	*-2013*	*-13929*	*15006*	*-6904*	*6330*	*-1417*	*-1100*
2008	*-1805*	*-13286*	*15117*	*-6971*	*6347*	*-1912*	*-1100*
2009	*-1303*	*-12208*	*15202*	*-6949*	*6408*	*-2655*	*-1100*
2010	***-270***	***-10451***	***15352***	***-6957***	***6483***	***-3598***	***-1100***
2011	*496*	*-10366*	*15479*	*-6964*	*6510*	*-3062*	*-1100*
2012	*1233*	*-9469*	*15567*	*-6954*	*6513*	*-3323*	*-1100*
2013	*1771*	*-8334*	*15538*	*-6988*	*6528*	*-3873*	*-1100*
2014	*2338*	*-7761*	*15529*	*-6999*	*6547*	*-3879*	*-1100*
2015	***3065***	***-7004***	***15588***	***-7047***	***6566***	***-3937***	***-1100***
2016	*3751*	*-6779*	*15658*	*-6960*	*6547*	*-3614*	*-1100*
2017	*4130*	*-6749*	*15686*	*-7067*	*6526*	*-3165*	*-1100*
2018	*4481*	*-6566*	*15685*	*-7081*	*6512*	*-2968*	*-1100*
2019	*4998*	*-5472*	*15695*	*-7095*	*6531*	*-3560*	*-1100*
2020	***5993***	***-3659***	***15723***	***-6986***	***6560***	***-4545***	***-1100***

D UK Gg CO2	Changes in woody biomass	HWP	Forest Conversion	Soils	Other	Other	NET Emission (+) Removal (-)
1990	-12226	-1587	164	14952	2442	-1100	2645
1991	-12616	-1344	137	15098	2416	-1100	2590
1992	-13118	-1130	107	14948	2368	-1100	2076
1993	-13478	-1059	124	14091	2321	-1100	899
1994	-13858	-942	132	14061	2392	-1100	685
1995	-13727	-1123	161	14159	2417	-1100	787
1996	-13661	-1098	185	13990	2299	-1100	616
1997	-13527	-1195	152	13674	2208	-1100	211
1998	-13459	-1289	159	13244	2060	-1100	-385
1999	-13665	-1161	297	12937	2142	-1100	-550
2000	-13411	-1314	223	12716	2099	-1100	-787
2001	-14009	-743	228	12522	2116	-1100	-986
2002	-14775	-133	180	12418	1922	-1100	-1489
2003	-15418	248	141	12482	2111	-1100	-1536
NIR Format	5A (Removals)	5A (Removals)	5B (Emissions)	5D (Emissions)	5E (Emissions)	5E (Removals)	
	Forest biomass, soils, litter.	Forest products	Deforestation	Effect of LUC (Net), liming of soils	Drainage of lowland soils, peat extraction	Non-forest biomass	

Table A1. 2: England data for 2003 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection, D: "NIR" summary,. (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) England **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**5659**	**-2632**	**7949**	**-2285**	**4034**	**-471**	**-935**
1991	5759	-2674	8036	-2240	3955	-384	-935
1992	5579	-2731	7990	-2321	3877	-302	-935
1993	4938	-2703	7622	-2579	3837	-303	-935
1994	4953	-2725	7625	-2541	3793	-265	-935
1995	**5085**	**-2654**	**7685**	**-2487**	**3768**	**-292**	**-935**
1996	4889	-2706	7622	-2604	3742	-230	-935
1997	4558	-2668	7492	-2727	3678	-282	-935
1998	4136	-2607	7309	-2925	3645	-352	-935
1999	4004	-2663	7181	-2969	3708	-318	-935
2000	**3765**	**-2664**	**7090**	**-3041**	**3622**	**-307**	**-935**
2001	3623	-2859	7025	-3072	3594	-130	-935
2002	3317	-3080	6999	-3242	3530	45	-935
2003	3328	-3241	7049	-3165	3475	146	-935
2004	*3102*	*-3446*	*6980*	*-3232*	*3469*	*265*	*-935*
2005	***2837***	***-3346***	***6813***	***-3306***	***3453***	***158***	***-935***
2006	*2473*	*-3225*	*6703*	*-3489*	*3395*	*23*	*-935*
2007	*2394*	*-2888*	*6661*	*-3528*	*3374*	*-292*	*-935*
2008	*2311*	*-2659*	*6648*	*-3610*	*3351*	*-484*	*-935*
2009	*2366*	*-2488*	*6615*	*-3573*	*3368*	*-621*	*-935*
2010	***2368***	***-2286***	***6561***	***-3632***	***3374***	***-715***	***-935***
2011	*2295*	*-2423*	*6529*	*-3711*	*3358*	*-523*	*-935*
2012	*2181*	*-2247*	*6483*	*-3815*	*3327*	*-632*	*-935*
2013	*2181*	*-1573*	*6405*	*-3846*	*3309*	*-1179*	*-935*
2014	*2225*	*-1530*	*6386*	*-3859*	*3300*	*-1137*	*-935*
2015	***2291***	***-1341***	***6375***	***-3914***	***3295***	***-1188***	***-935***
2016	*2283*	*-1331*	*6365*	*-3969*	*3264*	*-1110*	*-935*
2017	*2222*	*-1425*	*6355*	*-4045*	*3232*	*-959*	*-935*
2018	*2241*	*-1505*	*6345*	*-4033*	*3207*	*-839*	*-935*
2019	*2243*	*-1471*	*6335*	*-4045*	*3206*	*-847*	*-935*
2020	***2385***	***-888***	***6326***	***-4063***	***3213***	***-1268***	***-935***

B (Low) England **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**5659**	**-2632**	**7949**	**-2285**	**4034**	**-471**	**-935**
1991	5759	-2674	8036	-2240	3955	-384	-935
1992	5579	-2731	7989	-2320	3877	-302	-935
1993	4938	-2703	7622	-2579	3837	-303	-935
1994	4953	-2725	7625	-2541	3793	-265	-935
1995	**5085**	**-2654**	**7684**	**-2487**	**3768**	**-292**	**-935**
1996	4889	-2706	7622	-2604	3742	-230	-935
1997	4558	-2668	7492	-2727	3678	-282	-935
1998	4136	-2607	7309	-2924	3645	-352	-935
1999	4004	-2663	7181	-2968	3708	-318	-935
2000	**3765**	**-2664**	**7090**	**-3041**	**3622**	**-307**	**-935**
2001	3623	-2859	7025	-3072	3594	-130	-935
2002	3317	-3080	6999	-3242	3530	45	-935
2003	3328	-3241	7048	-3165	3475	146	-935
2004	*2975*	*-3474*	*6924*	*-3238*	*3433*	*265*	*-935*
2005	***2618***	***-3376***	***6700***	***-3311***	***3382***	***158***	***-935***
2006	*2175*	*-3242*	*6532*	*-3494*	*3290*	*23*	*-935*
2007	*1986*	*-2922*	*6433*	*-3534*	*3235*	*-292*	*-935*
2008	*1760*	*-2745*	*6363*	*-3618*	*3179*	*-484*	*-935*
2009	*1638*	*-2659*	*6272*	*-3583*	*3164*	*-621*	*-935*
2010	***1123***	***-2565***	***5935***	***-3667***	***3070***	***-715***	***-935***
2011	*671*	*-2819*	*5744*	*-3759*	*2962*	*-523*	*-935*
2012	*425*	*-2756*	*5701*	*-3857*	*2904*	*-632*	*-935*
2013	*362*	*-2188*	*5658*	*-3862*	*2869*	*-1179*	*-935*
2014	*254*	*-2245*	*5613*	*-3886*	*2843*	*-1137*	*-935*
2015	***163***	***-2147***	***5567***	***-3957***	***2823***	***-1188***	***-935***
2016	*9*	*-2224*	*5520*	*-4028*	*2785*	*-1110*	*-935*
2017	*-196*	*-2401*	*5473*	*-4120*	*2747*	*-959*	*-935*
2018	*-319*	*-2562*	*5425*	*-4124*	*2715*	*-839*	*-935*
2019	*-459*	*-2607*	*5377*	*-4153*	*2707*	*-847*	*-935*
2020	***-460***	***-2104***	***5330***	***-4187***	***2705***	***-1268***	***-935***

C (High) England **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**5659**	**-2632**	**7949**	**-2285**	**4034**	**-471**	**-935**
1991	5759	-2674	8036	-2240	3955	-384	-935
1992	5579	-2731	7989	-2320	3877	-302	-935
1993	4938	-2703	7622	-2579	3837	-303	-935
1994	4953	-2725	7625	-2541	3793	-265	-935
1995	**5085**	**-2654**	**7684**	**-2487**	**3768**	**-292**	**-935**
1996	4889	-2706	7622	-2604	3742	-230	-935
1997	4558	-2668	7492	-2727	3678	-282	-935
1998	4136	-2607	7309	-2924	3645	-352	-935
1999	4004	-2663	7181	-2968	3708	-318	-935
2000	**3765**	**-2664**	**7090**	**-3041**	**3622**	**-307**	**-935**
2001	3623	-2859	7025	-3072	3594	-130	-935
2002	3317	-3080	6999	-3242	3530	45	-935
2003	3328	-3241	7048	-3165	3475	146	-935
2004	*3231*	*-3429*	*7040*	*-3212*	*3502*	*265*	*-935*
2005	***3082***	***-3328***	***6933***	***-3266***	***3520***	***158***	***-935***
2006	*2826*	*-3215*	*6885*	*-3427*	*3495*	*23*	*-935*
2007	*2875*	*-2867*	*6904*	*-3444*	*3508*	*-292*	*-935*
2008	*2940*	*-2608*	*6953*	*-3503*	*3518*	*-484*	*-935*
2009	*3151*	*-2387*	*6981*	*-3442*	*3556*	*-621*	*-935*
2010	***3425***	***-2122***	***7053***	***-3450***	***3595***	***-715***	***-935***
2011	*3594*	*-2192*	*7127*	*-3479*	*3595*	*-523*	*-935*
2012	*3710*	*-1949*	*7178*	*-3533*	*3581*	*-632*	*-935*
2013	*3859*	*-1213*	*7122*	*-3515*	*3579*	*-1179*	*-935*
2014	*3986*	*-1113*	*7087*	*-3504*	*3587*	*-1137*	*-935*
2015	***4207***	***-870***	***7108***	***-3506***	***3598***	***-1188***	***-935***
2016	*4366*	*-809*	*7139*	*-3503*	*3584*	*-1110*	*-935*
2017	*4412*	*-854*	*7136*	*-3544*	*3569*	*-959*	*-935*
2018	*4497*	*-887*	*7109*	*-3512*	*3561*	*-839*	*-935*
2019	*4578*	*-806*	*7090*	*-3500*	*3576*	*-847*	*-935*
2020	***4822***	***-177***	***7088***	***-3485***	***3599***	***-1268***	***-935***

D England Gg CO2	Changes in woody biomass	HWP	Forest Conversion	Soils	Other	Other	NET Emission (+) Removal (-)
1990	-2632	-471	118	7701	1879	-935	5659
1991	-2674	-384	98	7793	1859	-935	5759
1992	-2731	-302	77	7671	1798	-935	5579
1993	-2703	-303	89	7032	1759	-935	4938
1994	-2725	-265	95	6999	1784	-935	4953
1995	-2654	-292	116	7061	1789	-935	5085
1996	-2706	-230	133	6929	1699	-935	4889
1997	-2668	-282	109	6689	1644	-935	4558
1998	-2607	-352	114	6368	1548	-935	4136
1999	-2663	-318	213	6137	1570	-935	4004
2000	-2664	-307	160	5970	1540	-935	3765
2001	-2859	-130	163	5824	1560	-935	3623
2002	-3080	45	129	5744	1414	-935	3317
2003	-3241	146	101	5789	1468	-935	3328
NIR Format	5A (Removals)	5A (Removals)	5B (Emissions)	5D (Emissions)	5E (Emissions)	5E (Removals)	
	Forest biomass, soils, litter.	Forest products	Deforestation	Effect of LUC (Net), liming of soils	Drainage of lowland soils, peat extraction	Non-forest biomass	

Table A1. 3: Scotland data for 2003 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection, D: "NIR" summary,. (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) Scotland **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**-3049**	**-7528**	**5357**	**-1637**	**1608**	**-714**	**-136**
1991	-3249	-7822	5422	-1666	1589	-635	-136
1992	-3583	-8244	5463	-1690	1570	-546	-136
1993	-4013	-8627	5451	-1769	1562	-495	-136
1994	-4265	-9020	5496	-1754	1554	-406	-136
1995	**-4359**	**-8998**	**5549**	**-1759**	**1550**	**-567**	**-136**
1996	-4360	-8922	5581	-1822	1546	-607	-136
1997	-4420	-8897	5600	-1902	1530	-615	-136
1998	-4561	-8949	5609	-2002	1523	-607	-136
1999	-4595	-9131	5626	-1985	1546	-516	-136
2000	**-4611**	**-8911**	**5647**	**-2036**	**1523**	**-699**	**-136**
2001	-4667	-9212	5670	-2075	1518	-431	-136
2002	-4853	-9637	5697	-2156	1501	-122	-136
2003	-4906	-10039	5735	-2045	1486	93	-136
2004	*-5204*	*-10459*	*5753*	*-2098*	*1487*	*247*	*-136*
2005	***-5275***	***-10129***	***5755***	***-2180***	***1485***	***-69***	***-136***
2006	*-5374*	*-9813*	*5764*	*-2280*	*1469*	*-379*	*-136*
2007	*-5284*	*-9400*	*5784*	*-2255*	*1465*	*-742*	*-136*
2008	*-5317*	*-9258*	*5807*	*-2304*	*1460*	*-887*	*-136*
2009	*-5270*	*-8786*	*5826*	*-2374*	*1468*	*-1269*	*-136*
2010	***-4861***	***-7679***	***5842***	***-2401***	***1472***	***-1959***	***-136***
2011	*-4551*	*-7584*	*5859*	*-2408*	*1468*	*-1750*	*-136*
2012	*-4177*	*-7001*	*5872*	*-2369*	*1461*	*-2004*	*-136*
2013	*-3992*	*-6710*	*5879*	*-2432*	*1457*	*-2050*	*-136*
2014	*-3754*	*-6397*	*5895*	*-2468*	*1456*	*-2105*	*-136*
2015	***-3491***	***-6048***	***5912***	***-2549***	***1456***	***-2126***	***-136***
2016	*-3184*	*-6047*	*5928*	*-2502*	*1448*	*-1875*	*-136*
2017	*-3054*	*-6175*	*5944*	*-2590*	*1439*	*-1536*	*-136*
2018	*-2963*	*-6179*	*5959*	*-2649*	*1433*	*-1391*	*-136*
2019	*-2745*	*-5510*	*5973*	*-2689*	*1434*	*-1817*	*-136*
2020	***-2263***	***-4697***	***5987***	***-2618***	***1438***	***-2237***	***-136***

B (Low) Scotland **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**-3049**	**-7528**	**5357**	**-1637**	**1608**	**-714**	**-136**
1991	-3249	-7822	5421	-1666	1589	-635	-136
1992	-3583	-8244	5463	-1690	1570	-546	-136
1993	-4013	-8627	5451	-1769	1562	-495	-136
1994	-4265	-9020	5496	-1754	1554	-406	-136
1995	**-4359**	**-8998**	**5549**	**-1759**	**1550**	**-567**	**-136**
1996	-4360	-8922	5580	-1822	1546	-607	-136
1997	-4420	-8897	5600	-1902	1530	-615	-136
1998	-4561	-8949	5609	-2002	1523	-607	-136
1999	-4595	-9131	5626	-1985	1546	-516	-136
2000	**-4611**	**-8911**	**5647**	**-2036**	**1523**	**-699**	**-136**
2001	-4667	-9212	5670	-2075	1518	-431	-136
2002	-4853	-9637	5697	-2156	1501	-122	-136
2003	-4906	-10039	5735	-2045	1486	93	-136
2004	*-5340*	*-10500*	*5687*	*-2124*	*1485*	*247*	*-136*
2005	***-5476***	***-10143***	***5625***	***-2232***	***1479***	***-69***	***-136***
2006	*-5581*	*-9741*	*5574*	*-2358*	*1458*	*-379*	*-136*
2007	*-5541*	*-9289*	*5535*	*-2358*	*1449*	*-742*	*-136*
2008	*-5678*	*-9164*	*5503*	*-2432*	*1438*	*-887*	*-136*
2009	*-5783*	*-8758*	*5469*	*-2527*	*1438*	*-1269*	*-136*
2010	***-5684***	***-7754***	***5294***	***-2554***	***1425***	***-1959***	***-136***
2011	*-5628*	*-7776*	*5195*	*-2565*	*1405*	*-1750*	*-136*
2012	*-5455*	*-7313*	*5157*	*-2540*	*1380*	*-2004*	*-136*
2013	*-5414*	*-7136*	*5163*	*-2616*	*1360*	*-2050*	*-136*
2014	*-5294*	*-6930*	*5200*	*-2671*	*1348*	*-2105*	*-136*
2015	***-5117***	***-6684***	***5234***	***-2749***	***1344***	***-2126***	***-136***
2016	*-4943*	*-6782*	*5266*	*-2748*	*1331*	*-1875*	*-136*
2017	*-4896*	*-7007*	*5295*	*-2832*	*1318*	*-1536*	*-136*
2018	*-4877*	*-7107*	*5322*	*-2872*	*1307*	*-1391*	*-136*
2019	*-4750*	*-6535*	*5347*	*-2912*	*1303*	*-1817*	*-136*
2020	***-4472***	***-5822***	***5370***	***-2947***	***1300***	***-2237***	***-136***

C (High) Scotland **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**-3049**	**-7528**	**5357**	**-1637**	**1608**	**-714**	**-136**
1991	-3249	-7822	5421	-1666	1589	-635	-136
1992	-3583	-8244	5463	-1690	1570	-546	-136
1993	-4013	-8627	5451	-1769	1562	-495	-136
1994	-4265	-9020	5496	-1754	1554	-406	-136
1995	**-4359**	**-8998**	**5549**	**-1759**	**1550**	**-567**	**-136**
1996	-4360	-8922	5580	-1822	1546	-607	-136
1997	-4420	-8897	5600	-1902	1530	-615	-136
1998	-4561	-8949	5609	-2002	1523	-607	-136
1999	-4595	-9131	5626	-1985	1546	-516	-136
2000	**-4611**	**-8911**	**5647**	**-2036**	**1523**	**-699**	**-136**
2001	-4667	-9212	5670	-2075	1518	-431	-136
2002	-4853	-9637	5697	-2156	1501	-122	-136
2003	-4906	-10039	5735	-2045	1486	93	-136
2004	*-5117*	*-10433*	*5780*	*-2069*	*1493*	*247*	*-136*
2005	***-5154***	***-10131***	***5809***	***-2123***	***1496***	***-69***	***-136***
2006	*-5248*	*-9871*	*5846*	*-2195*	*1487*	*-379*	*-136*
2007	*-5116*	*-9479*	*5892*	*-2142*	*1490*	*-742*	*-136*
2008	*-5080*	*-9329*	*5942*	*-2163*	*1492*	*-887*	*-136*
2009	*-4932*	*-8817*	*5988*	*-2205*	*1507*	*-1269*	*-136*
2010	***-4377***	***-7649***	***6045***	***-2206***	***1528***	***-1959***	***-136***
2011	*-3938*	*-7483*	*6077*	*-2188*	*1542*	*-1750*	*-136*
2012	*-3433*	*-6828*	*6106*	*-2122*	*1551*	*-2004*	*-136*
2013	*-3122*	*-6468*	*6129*	*-2160*	*1563*	*-2050*	*-136*
2014	*-2780*	*-6090*	*6156*	*-2175*	*1570*	*-2105*	*-136*
2015	***-2407***	***-5680***	***6190***	***-2230***	***1574***	***-2126***	***-136***
2016	*-1990*	*-5619*	*6226*	*-2156*	*1570*	*-1875*	*-136*
2017	*-1761*	*-5690*	*6256*	*-2221*	*1565*	*-1536*	*-136*
2018	*-1581*	*-5636*	*6282*	*-2260*	*1560*	*-1391*	*-136*
2019	*-1272*	*-4909*	*6309*	*-2280*	*1562*	*-1817*	*-136*
2020	***-694***	***-4038***	***6337***	***-2186***	***1565***	***-2237***	***-136***

D Scotland Gg CO2	Changes in woody biomass	HWP	Forest Conversion	Soils	Other	Other	NET Emission (+) Removal (-)
1990	-7528	-714	37	5213	79	-136	-3049
1991	-7822	-635	31	5241	73	-136	-3249
1992	-8244	-546	24	5233	86	-136	-3583
1993	-8627	-495	28	5138	78	-136	-4013
1994	-9020	-406	30	5143	124	-136	-4265
1995	-8998	-567	36	5161	143	-136	-4359
1996	-8922	-607	42	5147	116	-136	-4360
1997	-8897	-615	34	5114	80	-136	-4420
1998	-8949	-607	36	5066	28	-136	-4561
1999	-9131	-516	67	5033	88	-136	-4595
2000	-8911	-699	50	5009	75	-136	-4611
2001	-9212	-431	51	4988	73	-136	-4667
2002	-9637	-122	40	4977	24	-136	-4853
2003	-10039	93	32	4985	159	-136	-4906
NIR Format	5A (Removals)	5A (Removals)	5B (Emissions)	5D (Emissions)	5E (Emissions)	5E (Removals)	
	Forest biomass, soils, litter.	Forest products	Deforestation	Effect of LUC (Net), liming of soils	Drainage of lowland soils, peat extraction	Non-forest biomass	

Table A1. 4: Wales data for 2003 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection, D: "NIR" summary,. (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) Wales Gg CO2/year	**5** NET	**5A** Forestland	**5B** Cropland	**5C** Grassland	**5E** Settlements	**5G** HWP	**5G** Non-forest biomass
1990	**-344**	**-1337**	**970**	**-344**	**727**	**-347**	**-15**
1991	-293	-1367	979	-331	723	-283	-15
1992	-280	-1393	985	-341	719	-236	-15
1993	-326	-1386	986	-404	717	-223	-15
1994	-305	-1393	992	-406	715	-199	-15
1995	**-242**	**-1324**	**999**	**-397**	**715**	**-220**	**-15**
1996	-206	-1310	1004	-410	714	-190	-15
1997	-193	-1247	1008	-433	711	-216	-15
1998	-192	-1186	1010	-466	710	-246	-15
1999	-176	-1163	1013	-489	716	-239	-15
2000	**-144**	**-1120**	**1017**	**-506**	**711**	**-231**	**-15**
2001	-129	-1200	1021	-521	710	-124	-15
2002	-129	-1295	1025	-530	706	-21	-15
2003	-137	-1393	1030	-525	703	62	-15
2004	*-166*	*-1460*	*1034*	*-541*	*703*	*112*	*-15*
2005	***-169***	***-1379***	***1035***	***-572***	***703***	***59***	***-15***
2006	*-147*	*-1177*	*1037*	*-594*	*700*	*-98*	*-15*
2007	*-96*	*-950*	*1040*	*-605*	*699*	*-266*	*-15*
2008	*-46*	*-787*	*1044*	*-610*	*698*	*-376*	*-15*
2009	*36*	*-500*	*1047*	*-619*	*701*	*-578*	*-15*
2010	***158***	***-200***	***1049***	***-631***	***702***	***-747***	***-15***
2011	*248*	*-163*	*1051*	*-642*	*702*	*-687*	*-15*
2012	*305*	*-228*	*1053*	*-655*	*701*	*-551*	*-15*
2013	*339*	*-249*	*1055*	*-673*	*700*	*-479*	*-15*
2014	*391*	*-205*	*1057*	*-681*	*700*	*-465*	*-15*
2015	***476***	***-110***	***1059***	***-688***	***700***	***-471***	***-15***
2016	*530*	*-90*	*1062*	*-694*	*698*	*-431*	*-15*
2017	*582*	*-27*	*1064*	*-701*	*696*	*-436*	*-15*
2018	*620*	*-3*	*1066*	*-707*	*695*	*-416*	*-15*
2019	*692*	*223*	*1068*	*-713*	*695*	*-567*	*-15*
2020	***812***	***510***	***1070***	***-719***	***697***	***-731***	***-15***

B (Low) Wales **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**-344**	**-1337**	**971**	**-344**	**727**	**-347**	**-15**
1991	-293	-1367	979	-331	723	-283	-15
1992	-280	-1393	985	-341	719	-236	-15
1993	-326	-1386	986	-404	717	-223	-15
1994	-305	-1393	992	-406	715	-199	-15
1995	**-242**	**-1324**	**999**	**-397**	**715**	**-220**	**-15**
1996	-206	-1310	1004	-410	714	-190	-15
1997	-193	-1247	1008	-433	711	-216	-15
1998	-192	-1186	1010	-466	710	-246	-15
1999	-176	-1163	1013	-489	716	-239	-15
2000	**-144**	**-1120**	**1017**	**-506**	**711**	**-231**	**-15**
2001	-129	-1200	1021	-521	710	-124	-15
2002	-129	-1295	1025	-530	706	-21	-15
2003	-137	-1393	1031	-525	703	62	-15
2004	*-187*	*-1462*	*1023*	*-543*	*697*	*112*	*-15*
2005	***-199***	***-1381***	***1024***	***-577***	***691***	***59***	***-15***
2006	*-187*	*-1178*	*1025*	*-602*	*681*	*-98*	*-15*
2007	*-144*	*-952*	*1027*	*-615*	*678*	*-266*	*-15*
2008	*-104*	*-792*	*1028*	*-623*	*674*	*-376*	*-15*
2009	*-35*	*-510*	*1029*	*-634*	*673*	*-578*	*-15*
2010	***45***	***-216***	***1009***	***-653***	***668***	***-747***	***-15***
2011	*106*	*-185*	*997*	*-666*	*661*	*-687*	*-15*
2012	*141*	*-257*	*985*	*-676*	*654*	*-551*	*-15*
2013	*167*	*-284*	*980*	*-686*	*649*	*-479*	*-15*
2014	*209*	*-245*	*982*	*-696*	*647*	*-465*	*-15*
2015	***287***	***-155***	***984***	***-705***	***650***	***-471***	***-15***
2016	*337*	*-140*	*986*	*-713*	*650*	*-431*	*-15*
2017	*385*	*-81*	*987*	*-719*	*649*	*-436*	*-15*
2018	*418*	*-62*	*987*	*-725*	*649*	*-416*	*-15*
2019	*485*	*160*	*988*	*-732*	*650*	*-567*	*-15*
2020	***602***	***443***	***991***	***-738***	***652***	***-731***	***-15***

C (High) Wales **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**-344**	**-1337**	**971**	**-344**	**727**	**-347**	**-15**
1991	-293	-1367	979	-331	723	-283	-15
1992	-280	-1393	985	-341	719	-236	-15
1993	-326	-1386	986	-404	717	-223	-15
1994	-305	-1393	992	-406	715	-199	-15
1995	**-242**	**-1324**	**999**	**-397**	**715**	**-220**	**-15**
1996	-206	-1310	1004	-410	714	-190	-15
1997	-193	-1247	1008	-433	711	-216	-15
1998	-192	-1186	1010	-466	710	-246	-15
1999	-176	-1163	1013	-489	716	-239	-15
2000	**-144**	**-1120**	**1017**	**-506**	**711**	**-231**	**-15**
2001	-129	-1200	1021	-521	710	-124	-15
2002	-129	-1295	1025	-530	706	-21	-15
2003	-137	-1393	1031	-525	703	62	-15
2004	*-152*	*-1459*	*1036*	*-537*	*711*	*112*	*-15*
2005	***-141***	***-1378***	***1040***	***-566***	***718***	***59***	***-15***
2006	*-110*	*-1176*	*1045*	*-584*	*718*	*-98*	*-15*
2007	*-48*	*-949*	*1051*	*-591*	*721*	*-266*	*-15*
2008	*14*	*-784*	*1058*	*-592*	*722*	*-376*	*-15*
2009	*109*	*-493*	*1064*	*-597*	*728*	*-578*	*-15*
2010	***272***	***-188***	***1088***	***-600***	***734***	***-747***	***-15***
2011	*401*	*-146*	*1112*	*-603*	*739*	*-687*	*-15*
2012	*486*	*-207*	*1122*	*-607*	*743*	*-551*	*-15*
2013	*543*	*-223*	*1130*	*-617*	*746*	*-479*	*-15*
2014	*607*	*-175*	*1134*	*-624*	*751*	*-465*	*-15*
2015	***711***	***-76***	***1138***	***-621***	***755***	***-471***	***-15***
2016	*783*	*-52*	*1142*	*-617*	*754*	*-431*	*-15*
2017	*845*	*15*	*1145*	*-618*	*753*	*-436*	*-15*
2018	*888*	*42*	*1148*	*-624*	*753*	*-416*	*-15*
2019	*968*	*272*	*1150*	*-628*	*754*	*-567*	*-15*
2020	***1097***	***563***	***1153***	***-629***	***757***	***-731***	***-15***

D **Wales** Gg CO2	Changes in woody biomass	HWP	Forest Conversion	Soils	Other	Other	NET Emission (+) Removal (-)
1990	-1337	-347	9	1345	0	-15	-344
1991	-1367	-283	8	1364	0	-15	-293
1992	-1393	-236	6	1357	0	-15	-280
1993	-1386	-223	7	1291	0	-15	-326
1994	-1393	-199	7	1294	0	-15	-305
1995	-1324	-220	9	1308	0	-15	-242
1996	-1310	-190	11	1299	0	-15	-206
1997	-1247	-216	9	1277	0	-15	-193
1998	-1186	-246	9	1245	0	-15	-192
1999	-1163	-239	17	1224	0	-15	-176
2000	-1120	-231	13	1209	0	-15	-144
2001	-1200	-124	13	1197	0	-15	-129
2002	-1295	-21	10	1191	0	-15	-129
2003	-1393	62	8	1200	0	-15	-137
NIR Format	5A (Removals)	5A (Removals)	5B (Emissions)	5D (Emissions)	5E (Emissions)	5E (Removals)	
	Forest biomass, soils, litter.	Forest products	Deforestation	Effect of LUC (Net), liming of soils	Drainage of lowland soils, peat extraction	Non-forest biomass	

Table A1. 5: Northern Ireland data for 2003 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection, D: "NIR" summary,. (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) N. Ireland **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**379**	**-729**	**1267**	**-664**	**574**	**-55**	**-15**
1991	373	-753	1256	-649	577	-43	-15
1992	361	-750	1244	-652	580	-46	-15
1993	300	-762	1228	-696	583	-38	-15
1994	301	-720	1218	-693	585	-73	-15
1995	**304**	**-751**	**1209**	**-684**	**588**	**-44**	**-15**
1996	293	-722	1199	-689	590	-71	-15
1997	266	-715	1189	-704	593	-83	-15
1998	232	-718	1179	-725	595	-84	-15
1999	217	-707	1170	-740	597	-89	-15
2000	**203**	**-717**	**1162**	**-749**	**599**	**-77**	**-15**
2001	187	-738	1154	-757	600	-58	-15
2002	176	-763	1147	-760	602	-36	-15
2003	179	-745	1142	-754	604	-53	-15
2004	*181*	*-702*	*1135*	*-763*	*605*	*-80*	*-15*
2005	***164***	***-706***	***1128***	***-784***	***607***	***-66***	***-15***
2006	*160*	*-650*	*1121*	*-798*	*608*	*-107*	*-15*
2007	*164*	*-627*	*1116*	*-803*	*609*	*-117*	*-15*
2008	*179*	*-559*	*1111*	*-804*	*610*	*-165*	*-15*
2009	*199*	*-509*	*1107*	*-809*	*611*	*-187*	*-15*
2010	***211***	***-496***	***1102***	***-816***	***613***	***-177***	***-15***
2011	*213*	*-558*	*1098*	*-822*	*614*	*-103*	*-15*
2012	*221*	*-506*	*1093*	*-829*	*615*	*-136*	*-15*
2013	*225*	*-459*	*1089*	*-841*	*615*	*-165*	*-15*
2014	*249*	*-420*	*1085*	*-845*	*616*	*-173*	*-15*
2015	***261***	***-423***	***1082***	***-848***	***617***	***-152***	***-15***
2016	*282*	*-350*	*1079*	*-852*	*618*	*-198*	*-15*
2017	*313*	*-278*	*1076*	*-855*	*619*	*-234*	*-15*
2018	*348*	*-150*	*1073*	*-857*	*619*	*-322*	*-15*
2019	*386*	*-100*	*1070*	*-860*	*620*	*-329*	*-15*
2020	***417***	***-85***	***1068***	***-863***	***621***	***-308***	***-15***

B (Low) N. Ireland Gg CO2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**	**5G Non-forest biomass**
1990	**379**	**-729**	**1267**	**-663**	**574**	**-55**	**-15**
1991	373	-753	1256	-649	577	-43	-15
1992	361	-750	1244	-652	580	-46	-15
1993	300	-762	1228	-696	583	-38	-15
1994	301	-720	1218	-693	585	-73	-15
1995	**304**	**-751**	**1209**	**-684**	**588**	**-44**	**-15**
1996	293	-722	1199	-689	590	-71	-15
1997	266	-715	1189	-704	593	-83	-15
1998	232	-718	1179	-725	595	-84	-15
1999	217	-707	1170	-740	597	-89	-15
2000	**203**	**-717**	**1162**	**-749**	**599**	**-77**	**-15**
2001	187	-738	1154	-757	600	-58	-15
2002	176	-763	1147	-760	602	-36	-15
2003	179	-745	1142	-754	604	-53	-15
2004	*155*	*-706*	*1133*	*-783*	*606*	*-80*	*-15*
2005	***119***	***-707***	***1122***	***-824***	***608***	***-66***	***-15***
2006	*100*	*-643*	*1112*	*-856*	*609*	*-107*	*-15*
2007	*85*	*-616*	*1103*	*-879*	*609*	*-117*	*-15*
2008	*78*	*-549*	*1095*	*-898*	*609*	*-165*	*-15*
2009	*71*	*-506*	*1087*	*-918*	*609*	*-187*	*-15*
2010	***49***	***-502***	***1073***	***-923***	***593***	***-177***	***-15***
2011	*33*	*-575*	*1063*	*-925*	*588*	*-103*	*-15*
2012	*32*	*-534*	*1053*	*-925*	*588*	*-136*	*-15*
2013	*31*	*-497*	*1043*	*-925*	*589*	*-165*	*-15*
2014	*43*	*-468*	*1034*	*-925*	*589*	*-173*	*-15*
2015	***41***	***-480***	***1024***	***-925***	***589***	***-152***	***-15***
2016	*49*	*-416*	*1015*	*-925*	*588*	*-198*	*-15*
2017	*66*	*-354*	*1006*	*-925*	*588*	*-234*	*-15*
2018	*88*	*-234*	*997*	*-925*	*587*	*-322*	*-15*
2019	*111*	*-194*	*992*	*-930*	*586*	*-329*	*-15*
2020	***122***	***-188***	***987***	***-940***	***585***	***-308***	***-15***

C (High) N. Ireland **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**	**5G** **Non-forest biomass**
1990	**379**	**-729**	**1267**	**-663**	**574**	**-55**	**-15**
1991	373	-753	1256	-649	577	-43	-15
1992	361	-750	1244	-652	580	-46	-15
1993	300	-762	1228	-696	583	-38	-15
1994	301	-720	1218	-693	585	-73	-15
1995	**304**	**-751**	**1209**	**-684**	**588**	**-44**	**-15**
1996	293	-722	1199	-689	590	-71	-15
1997	266	-715	1189	-704	593	-83	-15
1998	232	-718	1179	-725	595	-84	-15
1999	217	-707	1170	-740	597	-89	-15
2000	**203**	**-717**	**1162**	**-749**	**599**	**-77**	**-15**
2001	187	-738	1154	-757	600	-58	-15
2002	176	-763	1147	-760	602	-36	-15
2003	179	-745	1142	-754	604	-53	-15
2004	*216*	*-699*	*1146*	*-742*	*606*	*-80*	*-15*
2005	***227***	***-706***	***1149***	***-744***	***608***	***-66***	***-15***
2006	*247*	*-656*	*1153*	*-740*	*610*	*-107*	*-15*
2007	*277*	*-635*	*1159*	*-727*	*612*	*-117*	*-15*
2008	*321*	*-566*	*1165*	*-712*	*614*	*-165*	*-15*
2009	*368*	*-512*	*1170*	*-705*	*617*	*-187*	*-15*
2010	***409***	***-492***	***1167***	***-700***	***626***	***-177***	***-15***
2011	*438*	*-545*	*1163*	*-695*	*634*	*-103*	*-15*
2012	*470*	*-485*	*1160*	*-692*	*639*	*-136*	*-15*
2013	*491*	*-430*	*1156*	*-695*	*640*	*-165*	*-15*
2014	*525*	*-383*	*1153*	*-697*	*639*	*-173*	*-15*
2015	***554***	***-379***	***1151***	***-691***	***639***	***-152***	***-15***
2016	*592*	*-299*	*1150*	*-685*	*639*	*-198*	*-15*
2017	*634*	*-221*	*1148*	*-684*	*639*	*-234*	*-15*
2018	*677*	*-86*	*1147*	*-686*	*638*	*-322*	*-15*
2019	*724*	*-29*	*1145*	*-687*	*638*	*-329*	*-15*
2020	***768***	***-7***	***1144***	***-686***	***638***	***-308***	***-15***

D **N. Ireland** Gg CO2	Changes in woody biomass	HWP	Forest Conversion	Soils	Other	Other	NET Emission (+) Removal (-)
1990	-729	-55	0	694	484	-15	379
1991	-753	-43	0	700	484	-15	373
1992	-750	-46	0	687	484	-15	361
1993	-762	-38	0	630	484	-15	300
1994	-720	-73	0	626	484	-15	301
1995	-751	-44	0	629	484	-15	304
1996	-722	-71	0	616	484	-15	293
1997	-715	-83	0	594	484	-15	266
1998	-718	-84	0	565	484	-15	232
1999	-707	-89	0	544	484	-15	217
2000	-717	-77	0	528	484	-15	203
2001	-738	-58	0	514	484	-15	187
2002	-763	-36	0	505	484	-15	176
2003	-745	-53	0	508	484	-15	179
NIR Format	5A (Removals)	5A (Removals)	5B (Emissions)	5D (Emissions)	5E (Emissions)	5E (Removals)	
	Forest biomass, soils, litter.	Forest products	Deforestation	Effect of LUC (Net), liming of soils	Drainage of lowland soils, peat extraction	Non-forest biomass	

APPENDIX 2

A.2. Sectoral Tables for Land Use Change and Forestry Sector submitted as UK 2003 Greenhouse Gas Inventory in format defined by IPCC 1996 Guidelines

Table A2 1 Sectoral report for land-use change and forestry, 1990. (Units are Gg CO2, NO = Not Occurring, NE = Not Established and IE = Included Elsewhere)

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1990
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**17,558.03**	**-14,912.79**	**2,645.24**	**0.72**	**0.00**	**0.1780**	**6.27**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-7,601.31**	**-7,601.31**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-6,014.29	-6,014.29				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,587.02	-1,587.02				
Harvested Wood (1)	NO	-1,587.02	-1,587.02				
			0.00				
B. Forest and Grassland Conversion (2)	**164.16**			**0.72**	**0.00**	**0.1780**	**6.27**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	164.16			0.72	0.005	0.18	6.27
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)			0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**16,602.30**	**-6,211.48**	**10,390.82**				
Cultivation of Mineral Soils	13,521.85	IE	13,521.85				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,430.45	NO	1,430.45				
Forest Soils	NO	-6,211.48	-6,211.48				
Other (please specify)(3)	1,650.00	0.00	1,650.00				
Lowland Drainage	1,650.00	NO	1,650.00				
			0.00				
E. Other (please specify)	**791.57**	**-1,100.00**	**-308.43**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	791.57	NO	791.57				
			0.00				

Table A2 2 Sectoral report for land-use change and forestry, 1991

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1991
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**17,650.27**	**-15,060.70**	**2,589.57**	**0.60**	**0.00**	**0.148**	**5.22**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-7,829.88**	**-7,829.88**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-6,485.54	-6,485.54				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,344.34	-1,344.34				
Harvested Wood (1)	NO	-1,344.34	-1,344.34				
			0.00				
B. Forest and Grassland Conversion (2)	**136.79**			**0.60**	**0.004**	**0.15**	**5.22**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	136.79			0.60	0.004	0.15	5.22
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)			0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**16,710.88**	**-6,130.82**	**10,580.06**				
Cultivation of Mineral Soils	13,325.60	IE	13,325.60				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,771.95	NO	1,771.95				
Forest Soils	NO	-6,130.82	-6,130.82				
Other (please specify)(3)	1,613.33	0.00	1,613.33				
Lowland Drainage	1,613.33	NO	1,613.33				
			0.00				
E. Other (please specify)	**802.60**	**-1,100.00**	**-297.40**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	802.60	NO	802.60				
			0.00				

Table A2 3 Sectoral report for land-use change and forestry, 1992

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1992
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**17,423.84**	**-15,347.96**	**2,075.88**	**0.47**	**0.00**	**0.12**	**4.09**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,080.44**	**-8,080.44**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-6,950.05	-6,950.05				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,130.39	-1,130.39				
Harvested Wood (1)	NO	-1,130.39	-1,130.39				
			0.00				
B. Forest and Grassland Conversion (2)	**107.14**			**0.47**	**0.003**	**0.12**	**4.09**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	107.14			0.47	0.003	0.12	4.09
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**16,525.13**	**-6,167.52**	**10,357.61**				
Cultivation of Mineral Soils	13,138.88	IE	13,138.88				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,809.58	NO	1,809.58				
Forest Soils	NO	-6,167.52	-6,167.52				
Other (please specify)(3)	1,576.67	0.00	1,576.67				
Lowland Drainage	1,576.67	NO	1,576.67				
			0.00				
E. Other (please specify)	**791.57**	**-1,100.00**	**-308.43**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	791.57	NO	791.57				
			0.00				

Table A2 4: Sectoral report for land-use change and forestry, 1993

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1993
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**16,535.62**	**-15,636.91**	**898.71**	**0.54**	**0.00**	**0.13**	**4.72**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,273.86**	**-8,273.86**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-7,215.04	-7,215.04				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,058.82	-1,058.82				
Harvested Wood (1)	NO	-1,058.82	-1,058.82				
			0.00				
B. Forest and Grassland Conversion (2)	**123.72**			**0.54**	**0.004**	**0.13**	**4.72**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	123.72			0.54	0.004	0.13	4.72
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**15,631.36**	**-6,263.05**	**9,368.31**				
Cultivation of Mineral Soils	12,961.04	IE	12,961.04				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,130.32	NO	1,130.32				
Forest Soils	NO	-6,263.05	-6,263.05				
Other (please specify)(3)	1,540.00	0.00	1,540.00				
Lowland Drainage	1,540.00	NO	1,540.00				
			0.00				
E. Other (please specify)	**780.54**	**-1,100.00**	**-319.46**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	780.54	NO	780.54				
			0.00				

Table A2 5 Sectoral report for land-use change and forestry, 1994

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1994
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**16,585.08**	**-15,900.14**	**684.94**	**0.57**	**0.00**	**0.14**	**5.03**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,502.87**	**-8,502.87**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-7,560.56	-7,560.56				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-942.31	-942.31				
Harvested Wood (1)	NO	-942.31	-942.31				
			0.00				
B. Forest and Grassland Conversion (2)	**131.65**			**0.57**	**0.004**	**0.14**	**5.03**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	131.65			0.57	0.004	0.14	5.03
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**15,564.64**	**-6,297.27**	**9,267.37**				
Cultivation of Mineral Soils	12,791.49	IE	12,791.49				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,269.82	NO	1,269.82				
Forest Soils	NO	-6,297.27	-6,297.27				
Other (please specify)(3)	1,503.33	0.00	1,503.33				
Lowland Drainage	1,503.33	NO	1,503.33				
			0.00				
E. Other (please specify)	**888.79**	**-1,100.00**	**-211.21**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	888.79	NO	888.79				
			0.00				

Table A2 6 Sectoral report for land-use change and forestry, 1995

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1995
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**16,736.88**	**-15,949.87**	**787.01**	**0.70**	**0.00**	**0.17**	**6.16**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,367.27**	**-8,367.27**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-7,244.51	-7,244.51				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,122.76	-1,122.76				
Harvested Wood (1)	NO	-1,122.76	-1,122.76				
			0.00				
B. Forest and Grassland Conversion (2)	**161.22**			**0.70**	**0.005**	**0.17**	**6.16**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	161.22			0.70	0.005	0.17	6.16
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**15,625.81**	**-6,482.60**	**9,143.21**				
Cultivation of Mineral Soils	12,629.70	IE	12,629.70				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,529.44	NO	1,529.44				
Forest Soils	NO	-6,482.60	-6,482.60				
Other (please specify)(3)	1,466.67	0.00	1,466.67				
Lowland Drainage	1,466.67	NO	1,466.67				
			0.00				
E. Other (please specify)	**949.85**	**-1,100.00**	**-150.15**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	949.85	NO	949.85				
			0.00				

Table A2 7 Sectoral report for land-use change and forestry, 1996

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1996
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**16,474.13**	**-15,858.62**	**615.51**	**0.81**	**0.01**	**0.20**	**7.06**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,234.85**	**-8,234.85**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-7,137.00	-7,137.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	NO	-1,097.85	-1,097.85				
Harvested Wood (1)	NO	-1,097.85	-1,097.85				
			0.00				
B. Forest and Grassland Conversion (2)	**184.85**			**0.81**	**0.006**	**0.2**	**7.06**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	184.85			0.81	0.006	0.2	7.06
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NO	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NO	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**15,420.30**	**-6,523.77**	**8,896.53**				
Cultivation of Mineral Soils	12,475.14	IE	12,475.14				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,515.16	NO	1,515.16				
Forest Soils	NO	-6,523.77	-6,523.77				
Other (please specify)(3)	1,430.00	0.00	1,430.00				
Lowland Drainage	1,430.00	NO	1,430.00				
			0.00				
E. Other (please specify)	**868.98**	**-1,100.00**	**-231.02**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	868.98	NO	868.98				
			0.00				

Table A2 8 Sectoral report for land-use change and forestry, 1997

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1997
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**16,033.97**	**-15,822.78**	**211.19**	**0.66**	**0.00**	**0.16**	**5.81**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,121.97**	**-8,121.97**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-6,926.63	-6,926.63				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,195.34	-1,195.34				
Harvested Wood (1)	NO	-1,195.34	-1,195.34				
			0.00				
B. Forest and Grassland Conversion (2)	**152.05**			**0.66**	**0.005**	**0.16**	**5.81**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	152.05			0.66	0.005	0.16	5.81
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**15,067.07**	**-6,600.81**	**8,466.26**				
Cultivation of Mineral Soils	12,327.36	IE	12,327.36				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,346.38	NO	1,346.38				
Forest Soils	NO	-6,600.81	-6,600.81				
Other (please specify)(3)	1,393.33	0.00	1,393.33				
Lowland Drainage	1,393.33	NO	1,393.33				
			0.00				
E. Other (please specify)	**814.85**	**-1,100.00**	**-285.15**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	814.85	NO	814.85				
			0.00				

Table A2 9 Sectoral report for land-use change and forestry, 1998

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1998
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**15,463.45**	**-15,848.86**	**-385.41**	**0.69**	**0.00**	**0.173**	**6.08**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,116.23**	**-8,116.23**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-6,826.87	-6,826.87				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,289.36	-1,289.36				
Harvested Wood (1)	NO	-1,289.36	-1,289.36				
			0.00				
B. Forest and Grassland Conversion (2)	**159.25**			**0.69**	**0.005**	**0.17**	**6.08**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	159.25			0.69	0.005	0.17	6.08
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**14,600.65**	**-6,632.63**	**7,968.02**				
Cultivation of Mineral Soils	12,185.93	IE	12,185.93				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	1,058.05	NO	1,058.05				
Forest Soils	NO	-6,632.63	-6,632.63				
Other (please specify)(3)	1,356.67	0.00	1,356.67				
Lowland Drainage	1,356.67	NO	1,356.67				
			0.00				
E. Other (please specify)	**703.55**	**-1,100.00**	**-396.45**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	703.55	NO	703.55				
			0.00				

Table A2 10 Sectoral report for land-use change and forestry, 1999

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
1999
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**15,375.75**	**-15,925.89**	**-550.14**	**1.30**	**0.01**	**0.32**	**11.33**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,331.92**	**-8,331.92**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-7,170.59	-7,170.59				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,161.33	-1,161.33				
Harvested Wood (1)	NO	-1,161.33	-1,161.33				
			0.00				
B. Forest and Grassland Conversion (2)	**296.79**			**1.30**	**0.009**	**0.32**	**11.33**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	296.79			1.30	0.009	0.32	11.33
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**14,257.37**	**-6,493.97**	**7,763.40**				
Cultivation of Mineral Soils	12,050.44	IE	12,050.44				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	886.93	NO	886.93				
Forest Soils	NO	-6,493.97	-6,493.97				
Other (please specify)(3)	1,320.00	0.00	1,320.00				
Lowland Drainage	1,320.00	NO	1,320.00				
			0.00				
E. Other (please specify)	**821.59**	**-1,100.00**	**-278.41**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	821.59	NO	821.59				
			0.00				

Table A2 11 Sectoral report for land-use change and forestry, 2000

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
2000
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**15,038.44**	**-15,825.52**	**-787.08**	**0.97**	**0.01**	**0.24**	**8.52**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,169.86**	**-8,169.86**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-6,855.59	-6,855.59				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-1,314.27	-1,314.27				
Harvested Wood (1)	NO	-1,314.27	-1,314.27				
			0.00				
B. Forest and Grassland Conversion (2)	**223.22**			**0.97**	**0.007**	**0.24**	**8.52**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	223.22			0.97	0.007	0.24	8.52
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**13,999.14**	**-6,555.66**	**7,443.48**				
Cultivation of Mineral Soils	11,921.63	IE	11,921.63				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	794.18	NO	794.18				
Forest Soils	NO	-6,555.66	-6,555.66				
Other (please specify)(3)	1,283.33	0.00	1,283.33				
Lowland Drainage	1,283.33	NO	1,283.33				
			0.00				
E. Other (please specify)	**816.08**	**-1,100.00**	**-283.92**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	816.08	NO	816.08				
			0.00				

Table A2 12 Sectoral report for land-use change and forestry, 2001

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
2001
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**14,866.00**	**-15,852.23**	**-986.23**	**0.99**	**0.01**	**0.25**	**8.69**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-8,518.77**	**-8,518.77**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-7,775.52	-7,775.52				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-743.25	-743.25				
Harvested Wood (1)	NO	-743.25	-743.25				
			0.00				
B. Forest and Grassland Conversion (2)	**227.56**			**0.99**	**0.007**	**0.25**	**8.69**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	227.56			0.99	0.007	0.25	8.69
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**13,783.76**	**-6,233.46**	**7,550.30**				
Cultivation of Mineral Soils	11,797.93	IE	11,797.93				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	724.50	NO	724.50				
Forest Soils	NO	-6,233.46	-6,233.46				
Other (please specify)(3)	1,261.33	0.00	1,261.33				
Lowland Drainage	1,261.33	NO	1,261.33				
			0.00				
E. Other (please specify)	**854.68**	**-1,100.00**	**-245.32**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	854.68	NO	854.68				
			0.00				

Table A2 13 Sectoral report for land-use change and forestry, 2002

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
2002
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**14,519.78**	**-16,008.39**	**-1,488.61**	**0.78**	**0.01**	**0.19**	**6.86**
A. Changes in Forest and Other Woody Biomass Stocks	**0.00**	**-9,049.06**	**-9,049.06**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-8,915.81	-8,915.81				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	0.00	-133.25	-133.25				
Harvested Wood (1)	NO	-133.25	-133.25				
			0.00				
B. Forest and Grassland Conversion (2)	**179.66**			**0.78**	**0.005**	**0.19**	**6.86**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	179.66			0.78	0.005	0.19	6.86
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**13,657.20**	**-5,859.33**	**7,797.87**				
Cultivation of Mineral Soils	11,679.04	IE	11,679.04				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	738.83	NO	738.83				
Forest Soils	NO	-5,859.33	-5,859.33				
Other (please specify)(3)	1,239.33	0.00	1,239.33				
Lowland Drainage	1,239.33	NO	1,239.33				
			0.00				
E. Other (please specify)	**682.92**	**-1,100.00**	**-417.08**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	682.92	NO	682.92				
			0.00				

Table A2 14 Sectoral report for land-use change and forestry, 2003

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY
(Sheet 1 of 1)

United Kingdom of Great Britain and Northern Ireland
2003
Submission 2003

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO2 emissions	CO2 removals	Net CO2 emissions/ removals	CH4	N2O	NOx	CO
	(Gg)						
Total Land-Use Change and Forestry	**14,982.16**	**-16,517.88**	**-1,535.72**	**0.61**	**0.00**	**0.15**	**5.37**
A. Changes in Forest and Other Woody Biomass Stocks	**247.98**	**-9,808.14**	**-9,560.16**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NO	-9,808.14	-9,808.14				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NO	NO	0.00				
5. Other (please specify)	247.98	0.00	247.98				
Harvested Wood (1)	247.98	NO	247.98				
			0.00				
B. Forest and Grassland Conversion (2)	**140.61**			**0.61**	**0.004**	**0.15**	**5.37**
1. Tropical Forests	NO			NO	NO	NO	NO
2. Temperate Forests	140.61			0.61	0.004	0.15	5.37
3. Boreal Forests	NO			NO	NO	NO	NO
4. Grasslands/Tundra	NO			NO	NO	NO	NO
5. Other (please specify)	0.00			0.00	0.00	0.00	0.00
C. Abandonment of Managed Lands	**0.00**	**0.00**	**0.00**				
1. Tropical Forests	NO	NO	0.00				
2. Temperate Forests	NE	NE	0.00				
3. Boreal Forests	NO	NO	0.00				
4. Grasslands/Tundra	NE	NE	0.00				
5. Other (please specify)	0.00	0.00	0.00				
			0.00				
D. CO2 Emissions and Removals from Soil	**13,699.68**	**-5,609.74**	**8,089.94**				
Cultivation of Mineral Soils	11,564.66	IE	11,564.66				
Cultivation of Organic Soils	IE	IE	0.00				
Liming of Agricultural Soils	917.69	NO	917.69				
Forest Soils	NO	-5,609.74	-5,609.74				
Other (please specify)(3)	1,217.33	0.00	1,217.33				
Lowland Drainage	1,217.33	NO	1,217.33				
			0.00				
E. Other (please specify)	**893.89**	**-1,100.00**	**-206.11**	**0.00**	**0.00**	**0.00**	**0.00**
Changes in Non-forest Biomass	NO	-1,100.00	-1,100.00				
Peat Extraction	893.89	NO	893.89				
			0.00				

APPENDIX 3

A.3. Sectoral Tables for Land Use Change and Forestry Sector submitted as UK 2003 Greenhouse Gas Inventory in format defined by IPCC LULUCF Good practice Guidance

Table A3. 1 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1990 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	2645.25	0.72	0.005
A. Forest Land	-12225.76	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-12225.76	0.00	0.00
B. Cropland	15543.69	0.00	0.00
1. Cropland remaining Cropland	1650.00	0.00	0.00
2. Land converted to Cropland	13126.79	0.00	0.00
C. Grassland	-4929.31	0.00	0.00
1. Grassland remaining Grassland	791.57	0.00	0.00
2. Land converted to Grassland	-6384.42	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6943.64	0.72	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6943.64	0.72	0.005
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2687.02	0.00	0.00
Harvested Wood Products (6)	-1587.02	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	742.33	0.72	0.005
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 2 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1991 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	2589.58	0.60	0.004
A. Forest Land	-12616.36	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-12616.36	0.00	0.00
B. Cropland	15693.14	0.00	0.00
1. Cropland remaining Cropland	1613.33	0.00	0.00
2. Land converted to Cropland	13129.82	0.00	0.00
C. Grassland	-4886.40	0.00	0.00
1. Grassland remaining Grassland	802.60	0.00	0.00
2. Land converted to Grassland	-6510.96	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6843.54	0.60	0.00
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6843.54	0.60	0.004
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2444.34	0.00	0.00
Harvested Wood Products (6)	-1344.34	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	698.30	0.60	0.004
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 3 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1992 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	2075.89	0.47	0.003
A. Forest Land	-13117.57	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13117.57	0.00	0.00
B. Cropland	15681.21	0.00	0.00
1. Cropland remaining Cropland	1576.67	0.00	0.00
2. Land converted to Cropland	13134.38	0.00	0.00
C. Grassland	-5003.27	0.00	0.00
1. Grassland remaining Grassland	791.57	0.00	0.00
2. Land converted to Grassland	-6634.26	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6745.90	0.47	0.00
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6745.90	0.47	0.003
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2230.39	0.00	0.00
Harvested Wood Products (6)	-1130.39	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	652.92	0.47	0.003
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 4 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1993 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	898.71	0.54	0.004
A. Forest Land	-13478.09	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13478.09	0.00	0.00
B. Cropland	15286.27	0.00	0.00
1. Cropland remaining Cropland	1540.00	0.00	0.00
2. Land converted to Cropland	13140.27	0.00	0.00
C. Grassland	-5449.55	0.00	0.00
1. Grassland remaining Grassland	780.54	0.00	0.00
2. Land converted to Grassland	-6754.42	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6698.91	0.54	0.00
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6698.91	0.54	0.004
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2158.82	0.00	0.00
Harvested Wood Products (6)	-1058.82	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	654.68	0.54	0.004
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 5 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1994 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	684.94	0.57	0.004
A. Forest Land	-13857.83	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13857.83	0.00	0.00
B. Cropland	15331.43	0.00	0.00
1. Cropland remaining Cropland	1503.33	0.00	0.00
2. Land converted to Cropland	13147.32	0.00	0.00
C. Grassland	-5393.73	0.00	0.00
1. Grassland remaining Grassland	888.79	0.00	0.00
2. Land converted to Grassland	-6871.55	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6647.37	0.57	0.00
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6647.37	0.57	0.004
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2042.31	0.00	0.00
Harvested Wood Products (6)	-942.31	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	648.63	0.57	0.004
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 6 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1995 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	786.99	0.70	0.005
A. Forest Land	-13727.12	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13727.12	0.00	0.00
B. Cropland	15441.99	0.00	0.00
1. Cropland remaining Cropland	1466.67	0.00	0.00
2. Land converted to Cropland	13155.35	0.00	0.00
C. Grassland	-5326.43	0.00	0.00
1. Grassland remaining Grassland	949.85	0.00	0.00
2. Land converted to Grassland	-6985.75	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6621.31	0.70	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6621.31	0.70	0.005
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2222.76	0.00	0.00
Harvested Wood Products (6)	-1122.76	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	665.05	0.70	0.005
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 7 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1996 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	615.51	0.81	0.006
A. Forest Land	-13660.77	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13660.77	0.00	0.00
B. Cropland	15406.55	0.00	0.00
1. Cropland remaining Cropland	1430.00	0.00	0.00
2. Land converted to Cropland	13164.23	0.00	0.00
C. Grassland	-5525.30	0.00	0.00
1. Grassland remaining Grassland	868.98	0.00	0.00
2. Land converted to Grassland	-7097.12	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6592.88	0.81	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6592.88	0.81	0.006
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2197.85	0.00	0.00
Harvested Wood Products (6)	-1097.85	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	676.25	0.81	0.006
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 8 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1997 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/ removals**	**CH_4**	**N_2O**
	(Gg)		
Total Land-Use Categories	211.21	0.66	0.005
A. Forest Land	-13527.43	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13527.43	0.00	0.00
B. Cropland	15288.99	0.00	0.00
1. Cropland remaining Cropland	1393.33	0.00	0.00
2. Land converted to Cropland	13173.83	0.00	0.00
C. Grassland	-5766.34	0.00	0.00
1. Grassland remaining Grassland	814.85	0.00	0.00
2. Land converted to Grassland	-7205.74	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6511.33	0.66	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6511.33	0.66	0.005
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2295.34	0.00	0.00
Harvested Wood Products (6)	-1195.34	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	631.75	0.66	0.005
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 9 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1998 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	-385.43	0.69	0.005
A. Forest Land	-13459.50	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13459.50	0.00	0.00
B. Cropland	15107.94	0.00	0.00
1. Cropland remaining Cropland	1356.67	0.00	0.00
2. Land converted to Cropland	13184.03	0.00	0.00
C. Grassland	-6117.37	0.00	0.00
1. Grassland remaining Grassland	703.55	0.00	0.00
2. Land converted to Grassland	-7311.72	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6472.87	0.69	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6472.87	0.69	0.005
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2389.36	0.00	0.00
Harvested Wood Products (6)	-1289.36	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	627.88	0.69	0.005
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 10 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1999 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	-550.14	1.30	0.009
A. Forest Land	-13664.56	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13664.56	0.00	0.00
B. Cropland	14990.22	0.00	0.00
1. Cropland remaining Cropland	1320.00	0.00	0.00
2. Land converted to Cropland	13194.71	0.00	0.00
C. Grassland	-6182.11	0.00	0.00
1. Grassland remaining Grassland	821.59	0.00	0.00
2. Land converted to Grassland	-7415.13	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6567.64	1.30	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6567.64	1.30	0.009
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2261.33	0.00	0.00
Harvested Wood Products (6)	-1161.33	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	754.97	1.30	0.009
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 11 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2000 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	-787.09	0.97	0.007
A. Forest Land	-13411.25	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-13411.25	0.00	0.00
B. Cropland	14916.50	0.00	0.00
1. Cropland remaining Cropland	1283.33	0.00	0.00
2. Land converted to Cropland	13207.39	0.00	0.00
C. Grassland	-6332.64	0.00	0.00
1. Grassland remaining Grassland	816.08	0.00	0.00
2. Land converted to Grassland	-7517.11	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6454.57	0.97	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6454.57	0.97	0.007
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-2414.27	0.00	0.00
Harvested Wood Products (6)	-1314.27	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	671.61	0.97	0.007
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 12 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2001 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	-986.24	0.99	0.005
A. Forest Land	-14008.99	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-14008.99	0.00	0.00
B. Cropland	14870.05	0.00	0.00
1. Cropland remaining Cropland	1261.33	0.00	0.00
2. Land converted to Cropland	13220.29	0.00	0.00
C. Grassland	-6425.91	0.00	0.00
1. Grassland remaining Grassland	854.68	0.00	0.00
2. Land converted to Grassland	-7616.66	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6421.86	0.99	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6421.86	0.99	0.005
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-1843.25	0.00	0.00
Harvested Wood Products (6)	-743.25	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	666.66	0.99	0.005
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 13 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2002 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	-1488.63	0.78	0.005
A. Forest Land	-14775.15	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-14775.15	0.00	0.00
B. Cropland	14868.79	0.00	0.00
1. Cropland remaining Cropland	1239.33	0.00	0.00
2. Land converted to Cropland	13233.35	0.00	0.00
C. Grassland	-6688.22	0.00	0.00
1. Grassland remaining Grassland	682.92	0.00	0.00
2. Land converted to Grassland	-7713.86	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6339.20	0.78	0.01
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6339.20	0.78	0.005
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-1233.25	0.00	0.00
Harvested Wood Products (6)	-133.25	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	610.01	0.78	0.005
Grassland converted to other Land-Use Categories	NO	NO	NO

Table A3. 14 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2003 for United Kingdom in Sectoral Report Table Format recommended by IPCC Good Practice Guidance for LULUCF.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/ removals	CH_4	N_2O
	(Gg)		
Total Land-Use Categories	-1535.71	0.61	0.004
A. Forest Land	-15417.88	0.00	0.00
1. Forest Land remaining Forest Land	0.00	0.00	0.00
2. Land converted to Forest Land	-15417.88	0.00	0.00
B. Cropland	14955.84	0.00	0.00
1. Cropland remaining Cropland	1217.33	0.00	0.00
2. Land converted to Cropland	13246.51	0.00	0.00
C. Grassland	-6489.19	0.00	0.00
1. Grassland remaining Grassland	893.89	0.00	0.00
2. Land converted to Grassland	-7808.77	0.00	0.00
D. Wetlands	0.00	0.00	0.00
1. Wetlands remaining Wetlands	0.00	0.00	0.00
2. Land converted to Wetlands	0.00	0.00	0.00
E. Settlements	6267.53	0.61	0.00
1. Settlements remaining Settlements	0.00	NO	NO
2. Land converted to Settlements	6267.53	0.61	0.004
F. Other Land	0.00	0.00	0.00
1. Other Land remaining Other Land		NO	NO
2. Land converted to Other Land	0.00	NO	NO
G. Other (please specify)	-852.02	0.00	0.00
Harvested Wood Products (6)	247.98	NO	NO
Changes in non-forest biomass	-1100.00	NO	NO
Information items			
Forest Land converted to other Land-Use Categories	562.67	0.61	0.004
Grassland converted to other Land-Use Categories	NO	NO	NO

APPENDIX 4

A.4. Estimated Removals of atmospheric carbon by post-1990 afforestation in the UK

The following notes apply to all Tables

Low Mid High refer to Emissions Scenarios

Low means more forestry - proportion of UK planting of 30,000 ha/year distributed by conifer & broadleaf to the four individual countries by proportions in 2002.

Mid means policy based or business as usual forestry –Planting of 4500 kha/yr broadleaf and 0.5 kha/year conifer in England, planting in Scotland to followed planned financial support through Woodland Grant Scheme (4.0-4.5 kha/year broadleaf, ~ 2.7 kha/year conifer), proportion of UK planting of 13 kha/year distributed across Wales and N. Ireland as per 2003.

High means less forestry - 0 kha/year conifer, 0 kha/year broadleaf

These data include, biomass, litter, soils and products

Products are small in the time period covered

Units are ktC per year

Projected deforestation follows 10 term autoregressive model fitted to 1990 - 2003 for short term variation: unadjusted for Mid scenario but with upward long term trend for High scenario and downward long term trend for Low scenario.

Table A4. 1 Removal of atmospheric carbon by post-1990 afforestation –United Kingdom A: Mid emissions scenario, B: Low emission scenario, C: High emission scenario

A (Mid) UK	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-111**	**0**	**164**	**15**	**1.5**	**13**	**83**
1991	-72	0	137	13	1.3	26	104
1992	78	0	107	10	1.0	38	234
1993	114	0	124	11	1.2	50	300
1994	36	0	132	12	1.2	60	241
1995	**-152**	**0**	**161**	**15**	**1.5**	**71**	**96**
1996	-366	0	185	17	1.7	80	-82
1997	-621	0	152	14	1.4	89	-364
1998	-883	0	159	15	1.5	98	-610
1999	-1117	0	297	27	2.8	106	-684
2000	**-1339**	**0**	**223**	**20**	**2.1**	**114**	**-980**
2001	-1538	0	228	21	2.1	121	-1166
2002	-1694	0	180	16	1.7	128	-1369
2003	-1867	0	141	13	1.3	135	-1577
2004	*-2074*	*0*	*168*	*15*	*1.6*	*141*	*-1747*
2005	***-2280***	***0***	***180***	***17***	***1.7***	***147***	***-1934***
2006	*-2480*	*0*	*131*	*12*	*1.2*	*152*	*-2183*
2007	*-2662*	*0*	*132*	*12*	*1.2*	*158*	*-2359*
2008	*-2825*	*0*	*128*	*12*	*1.2*	*163*	***-2521***
2009	*-2976*	*0*	*178*	*16*	*1.7*	*168*	***-2612***
2010	***-3163***	***0***	***211***	***19***	***2.0***	***172***	***-2758***
2011	*-3340*	*0*	*212*	*19*	*2.0*	*177*	***-2929***
2012	*-3515*	*0*	*192*	*18*	*1.8*	*181*	***-3123***
2013	*-3670*	*-11*	*186*	*17*	*1.7*	*185*	*-3280*
2014	*-3816*	*-16*	*194*	*18*	*1.8*	*188*	*-3414*
2015	***-3663***	***-214***	***204***	***19***	***1.9***	***192***	***-3246***
2016	*-3938*	*-86*	*178*	*16*	*1.7*	*195*	*-3546*
2017	*-4184*	*-29*	*150*	*14*	*1.4*	*198*	*-3821*
2018	*-4434*	*3*	*132*	*12*	*1.2*	*202*	*-4087*
2019	*-4709*	*36*	*145*	*13*	*1.3*	*204*	*-4345*
2020	***-4423***	***-263***	***168***	***15***	***1.6***	***207***	***-4031***

B (Low) UK	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-111**	**0**	**164**	**15**	**1.5**	**13**	**83**
1991	-72	0	137	13	1.3	26	104
1992	78	0	107	10	1.0	38	234
1993	114	0	124	11	1.2	50	300
1994	36	0	132	12	1.2	60	241
1995	**-152**	**0**	**161**	**15**	**1.5**	**71**	**96**
1996	-366	0	185	17	1.7	80	-82
1997	-621	0	152	14	1.4	89	-364
1998	-883	0	159	15	1.5	98	-610
1999	-1117	0	297	27	2.8	106	-684
2000	**-1339**	**0**	**223**	**20**	**2.1**	**114**	**-980**
2001	-1538	0	228	21	2.1	121	-1166
2002	-1694	0	180	16	1.7	128	-1369
2003	-1867	0	141	13	1.3	135	-1577
2004	*-2145*	*0*	*161*	*15*	*1.5*	*141*	*-1827*
2005	***-2317***	***0***	***166***	***15***	***1.5***	***147***	***-1988***
2006	*-2406*	*0*	*109*	*10*	*1.0*	*150*	*-2136*
2007	*-2558*	*0*	*103*	*9*	*1.0*	*153*	*-2293*
2008	*-2788*	*0*	*90*	*8*	*0.8*	*155*	***-2533***
2009	*-3096*	*0*	*133*	*12*	*1.2*	*159*	***-2790***
2010	***-3502***	***0***	***158***	***15***	***1.5***	***163***	***-3165***
2011	*-3923*	*0*	*151*	*14*	*1.4*	*166*	***-3591***
2012	*-4341*	*0*	*123*	*11*	*1.1*	*169*	***-4037***
2013	*-4725*	*-11*	*109*	*10*	*1.0*	*171*	*-4435*
2014	*-5085*	*-16*	*109*	*10*	*1.0*	*173*	*-4793*
2015	***-5133***	***-214***	***111***	***10***	***1.0***	***175***	***-4836***
2016	*-5599*	*-86*	*77*	*7*	*0.7*	*176*	*-5337*
2017	*-6029*	*-29*	*41*	*4*	*0.4*	*177*	*-5807*
2018	*-6458*	*3*	*14*	*1*	*0.1*	*177*	*-6266*
2019	*-6913*	*36*	*19*	*2*	*0.2*	*177*	*-6715*
2020	***-6808***	***-263***	***34***	***3***	***0.3***	***177***	***-6593***

C (High) UK	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-111**	**0**	**164**	**15**	**1.5**	**13**	**83**
1991	-72	0	137	13	1.3	26	104
1992	78	0	107	10	1.0	38	234
1993	114	0	124	11	1.2	50	300
1994	36	0	132	12	1.2	60	241
1995	**-152**	**0**	**161**	**15**	**1.5**	**71**	**96**
1996	-366	0	185	17	1.7	80	-82
1997	-621	0	152	14	1.4	89	-364
1998	-883	0	159	15	1.5	98	-610
1999	-1117	0	297	27	2.8	106	-684
2000	**-1339**	**0**	**223**	**20**	**2.1**	**114**	**-980**
2001	-1538	0	228	21	2.1	121	-1166
2002	-1694	0	180	16	1.7	128	-1369
2003	-1867	0	141	13	1.3	135	-1577
2004	-2023	0	176	16	1.6	142	-1689
2005	**-2253**	**0**	**195**	**18**	**1.8**	**148**	**-1891**
2006	-2519	0	153	14	1.4	153	-2198
2007	-2708	0	162	15	1.5	157	-2373
2008	-2823	0	165	15	1.5	162	***-2480***
2009	-2871	0	224	21	2.1	168	***-2457***
2010	**-2916**	**0**	**264**	**24**	**2.5**	**174**	***-2451***
2011	-2934	0	273	25	2.5	180	***-2453***
2012	-2951	0	261	24	2.4	186	***-2478***
2013	-2955	-11	263	24	2.4	191	-2474
2014	-2958	-16	279	26	2.6	196	-2455
2015	**-2670**	**-214**	**297**	**27**	**2.8**	**201**	**-2142**
2016	-2816	-86	280	26	2.6	206	-2302
2017	-2936	-29	259	24	2.4	210	-2440
2018	-3060	3	249	23	2.3	213	-2572
2019	-3210	36	270	25	2.5	217	-2695
2020	**-2795**	**-263**	**301**	**28**	**2.8**	**221**	**-2243**

Table A4. 2 Removal of atmospheric carbon by post-1990 afforestation –England A: Mid emissions scenario, B: Low emission scenario, C: High emission scenario

A (Mid) England	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-15**	**0**	**118**	**11**	**1.1**	**10**	**124**
1991	-20	0	98	9	0.9	19	107
1992	-14	0	77	7	0.7	27	99
1993	-25	0	89	8	0.8	36	109
1994	-55	0	95	9	0.9	43	93
1995	**-93**	**0**	**116**	**11**	**1.1**	**51**	**85**
1996	-147	0	133	12	1.2	58	57
1997	-219	0	109	10	1.0	64	-35
1998	-296	0	114	10	1.1	70	-100
1999	-373	0	213	20	2.0	76	-62
2000	**-442**	**0**	**160**	**15**	**1.5**	**82**	**-184**
2001	-498	0	163	15	1.5	87	-231
2002	-544	0	129	12	1.2	92	-310
2003	-594	0	101	9	0.9	97	-387
2004	*-645*	*0*	*121*	*11*	*1.1*	*101*	*-411*
2005	***-700***	***0***	***129***	***12***	***1.2***	***105***	***-452***
2006	*-758*	*0*	*94*	*9*	*0.9*	*109*	*-545*
2007	*-815*	*0*	*95*	*9*	*0.9*	*113*	*-597*
2008	*-868*	*0*	*92*	*8*	*0.9*	*117*	***-650***
2009	*-919*	*0*	*128*	*12*	*1.2*	*120*	***-657***
2010	***-971***	***0***	***152***	***14***	***1.4***	***124***	***-680***
2011	*-1024*	*0*	*153*	*14*	*1.4*	*127*	***-729***
2012	*-1077*	*0*	*138*	*13*	*1.3*	*130*	***-795***
2013	*-1132*	*0*	*134*	*12*	*1.2*	*133*	*-852*
2014	*-1185*	*0*	*139*	*13*	*1.3*	*135*	*-897*
2015	***-1224***	***-14***	***147***	***13***	***1.4***	***138***	***-925***
2016	*-1292*	*-8*	*128*	*12*	*1.2*	*140*	*-1011*
2017	*-1364*	*-1*	*108*	*10*	*1.0*	*143*	*-1103*
2018	*-1427*	*-3*	*95*	*9*	*0.9*	*145*	*-1178*
2019	*-1509*	*3*	*104*	*10*	*1.0*	*147*	*-1248*
2020	***-1526***	***-29***	***120***	***11***	***1.1***	***149***	***-1244***

B (Low) England	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
1990	**-15**	**0**	**118**	**11**	**1.1**	**10**	**124**
1991	-20	0	98	9	0.9	19	107
1992	-14	0	77	7	0.7	27	99
1993	-25	0	89	8	0.8	36	109
1994	-55	0	95	9	0.9	43	93
1995	**-93**	**0**	**116**	**11**	**1.1**	**51**	**85**
1996	-147	0	133	12	1.2	58	57
1997	-219	0	109	10	1.0	64	-35
1998	-296	0	114	10	1.1	70	-100
1999	-373	0	213	20	2.0	76	-62
2000	**-442**	**0**	**160**	**15**	**1.5**	**82**	**-184**
2001	-498	0	163	15	1.5	87	-231
2002	-544	0	129	12	1.2	92	-310
2003	-594	0	101	9	0.9	97	-387
2004	*-673*	*0*	*116*	*11*	*1.1*	*101*	*-445*
2005	***-730***	***0***	***119***	***11***	***1.1***	***105***	***-493***
2006	*-775*	*0*	*78*	*7*	*0.7*	*108*	*-581*
2007	*-849*	*0*	*74*	*7*	*0.7*	*110*	*-658*
2008	*-954*	*0*	*65*	*6*	*0.6*	*112*	***-771***
2009	*-1090*	*0*	*96*	*9*	*0.9*	*114*	***-870***
2010	***-1250***	***0***	***114***	***10***	***1.1***	***117***	***-1008***
2011	*-1419*	*0*	*109*	*10*	*1.0*	*119*	***-1180***
2012	*-1585*	*0*	*88*	*8*	*0.8*	*121*	***-1367***
2013	*-1748*	*0*	*78*	*7*	*0.7*	*123*	*-1539*
2014	*-1899*	*0*	*78*	*7*	*0.7*	*124*	*-1689*
2015	***-2031***	***-14***	***80***	***7***	***0.7***	***125***	***-1817***
2016	*-2185*	*-8*	*56*	*5*	*0.5*	*126*	*-1998*
2017	*-2340*	*-1*	*29*	*3*	*0.3*	*127*	*-2181*
2018	*-2484*	*-3*	*10*	*1*	*0.1*	*127*	*-2345*
2019	*-2645*	*3*	*14*	*1*	*0.1*	*127*	*-2503*
2020	***-2742***	***-29***	***25***	***2***	***0.2***	***127***	***-2587***

C (High) England	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-15**	**0**	**118**	**11**	**1.1**	**10**	**124**
1991	-20	0	98	9	0.9	19	107
1992	-14	0	77	7	0.7	27	99
1993	-25	0	89	8	0.8	36	109
1994	-55	0	95	9	0.9	43	93
1995	**-93**	**0**	**116**	**11**	**1.1**	**51**	**85**
1996	-147	0	133	12	1.2	58	57
1997	-219	0	109	10	1.0	64	-35
1998	-296	0	114	10	1.1	70	-100
1999	-373	0	213	20	2.0	76	-62
2000	**-442**	**0**	**160**	**15**	**1.5**	**82**	**-184**
2001	-498	0	163	15	1.5	87	-231
2002	-544	0	129	12	1.2	92	-310
2003	-594	0	101	9	0.9	97	-387
2004	*-628*	*0*	*126*	*12*	*1.2*	*102*	*-388*
2005	***-682***	***0***	***140***	***13***	***1.3***	***106***	***-422***
2006	*-748*	*0*	*110*	*10*	*1.0*	*110*	*-517*
2007	*-794*	*0*	*116*	*11*	*1.1*	*113*	*-553*
2008	*-817*	*0*	*119*	*11*	*1.1*	*116*	***-570***
2009	*-818*	*0*	*161*	*15*	*1.5*	*120*	***-521***
2010	***-807***	***0***	***190***	***17***	***1.8***	***125***	***-473***
2011	*-792*	*0*	*196*	*18*	*1.8*	*129*	***-446***
2012	*-779*	*0*	*187*	*17*	*1.7*	*133*	***-439***
2013	*-772*	*0*	*189*	*17*	*1.8*	*137*	*-427*
2014	*-767*	*0*	*200*	*18*	*1.9*	*141*	*-406*
2015	***-753***	***-14***	***214***	***20***	***2.0***	***145***	***-373***
2016	*-770*	*-8*	*201*	*18*	*1.9*	*148*	*-401*
2017	*-793*	*-1*	*186*	*17*	*1.7*	*151*	*-437*
2018	*-809*	*-3*	*179*	*16*	*1.7*	*153*	*-459*
2019	*-844*	*3*	*194*	*18*	*1.8*	*156*	*-475*
2020	***-815***	***-29***	***216***	***20***	***2.0***	***159***	***-418***

Table A4. 3 Removal of atmospheric carbon by post-1990 afforestation –Scotland A: Mid emissions scenario, B: Low emission scenario, C: High emission scenario

A (Mid) Scotland	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
1990	**-87**	**0**	**37**	**3**	**0.3**	**3**	**-43**
1991	-41	0	31	3	0.3	6	-1
1992	90	0	24	2	0.2	9	125
1993	132	0	28	3	0.3	11	174
1994	97	0	30	3	0.3	14	143
1995	**-37**	**0**	**36**	**3**	**0.3**	**16**	**18**
1996	-182	0	42	4	0.4	18	-118
1997	-339	0	34	3	0.3	20	-281
1998	-499	0	36	3	0.3	22	-438
1999	-631	0	67	6	0.6	24	-534
2000	**-762**	**0**	**50**	**5**	**0.5**	**26**	**-681**
2001	-890	0	51	5	0.5	27	-806
2002	-985	0	40	4	0.4	29	-912
2003	-1092	0	32	3	0.3	30	-1027
2004	*-1233*	*0*	*38*	*3*	*0.4*	*32*	*-1160*
2005	***-1370***	***0***	***41***	***4***	***0.4***	***33***	***-1292***
2006	*-1498*	*0*	*29*	*3*	*0.3*	*34*	*-1431*
2007	*-1611*	*0*	*30*	*3*	*0.3*	*35*	*-1543*
2008	*-1706*	*0*	*29*	*3*	*0.3*	*37*	***-1638***
2009	*-1791*	*0*	*40*	*4*	*0.4*	*38*	***-1709***
2010	***-1910***	***0***	***48***	***4***	***0.4***	***39***	***-1818***
2011	*-2019*	*0*	*48*	*4*	*0.4*	*40*	***-1927***
2012	*-2126*	*0*	*43*	*4*	*0.4*	*41*	***-2038***
2013	*-2229*	*0*	*42*	*4*	*0.4*	*42*	*-2142*
2014	*-2324*	*0*	*44*	*4*	*0.4*	*42*	*-2234*
2015	***-2115***	***-191***	***46***	***4***	***0.4***	***43***	***-2021***
2016	*-2294*	*-79*	*40*	*4*	*0.4*	*44*	*-2206*
2017	*-2460*	*-24*	*34*	*3*	*0.3*	*45*	*-2379*
2018	*-2642*	*16*	*30*	*3*	*0.3*	*45*	*-2564*
2019	*-2824*	*42*	*33*	*3*	*0.3*	*46*	*-2743*
2020	***-2515***	***-222***	***38***	***3***	***0.4***	***47***	***-2427***

B (Low) Scotland	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
1990	**-87**	**0**	**37**	**3**	**0.3**	**3**	**-43**
1991	-41	0	31	3	0.3	6	-1
1992	90	0	24	2	0.2	9	125
1993	132	0	28	3	0.3	11	174
1994	97	0	30	3	0.3	14	143
1995	**-37**	**0**	**36**	**3**	**0.3**	**16**	**18**
1996	-182	0	42	4	0.4	18	-118
1997	-339	0	34	3	0.3	20	-281
1998	-499	0	36	3	0.3	22	-438
1999	-631	0	67	6	0.6	24	-534
2000	**-762**	**0**	**50**	**5**	**0.5**	**26**	**-681**
2001	-890	0	51	5	0.5	27	-806
2002	-985	0	40	4	0.4	29	-912
2003	-1092	0	32	3	0.3	30	-1027
2004	*-1271*	*0*	*36*	*3*	*0.3*	*32*	*-1199*
2005	***-1375***	***0***	***37***	***3***	***0.3***	***33***	***-1301***
2006	*-1413*	*0*	*25*	*2*	*0.2*	*34*	*-1353*
2007	*-1482*	*0*	*23*	*2*	*0.2*	*34*	*-1422*
2008	*-1588*	*0*	*20*	*2*	*0.2*	*35*	***-1531***
2009	*-1733*	*0*	*30*	*3*	*0.3*	*36*	***-1665***
2010	***-1948***	***0***	***36***	***3***	***0.3***	***37***	***-1872***
2011	*-2169*	*0*	*34*	*3*	*0.3*	*37*	***-2094***
2012	*-2387*	*0*	*28*	*3*	*0.3*	*38*	***-2319***
2013	*-2597*	*0*	*25*	*2*	*0.2*	*38*	*-2532*
2014	*-2792*	*0*	*24*	*2*	*0.2*	*39*	*-2727*
2015	***-2677***	***-191***	***25***	***2***	***0.2***	***39***	***-2610***
2016	*-2946*	*-79*	*17*	*2*	*0.2*	*40*	*-2887*
2017	*-3199*	*-24*	*9*	*1*	*0.1*	*40*	*-3149*
2018	*-3466*	*16*	*3*	*0*	*0.0*	*40*	*-3423*
2019	*-3735*	*42*	*4*	*0*	*0.0*	*40*	*-3691*
2020	***-3514***	***-222***	***8***	***1***	***0.1***	***40***	***-3466***

C (High) Scotland	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-87**	**0**	**37**	**3**	**0.3**	**3**	**-43**
1991	-41	0	31	3	0.3	6	-1
1992	90	0	24	2	0.2	9	125
1993	132	0	28	3	0.3	11	174
1994	97	0	30	3	0.3	14	143
1995	**-37**	**0**	**36**	**3**	**0.3**	**16**	**18**
1996	-182	0	42	4	0.4	18	-118
1997	-339	0	34	3	0.3	20	-281
1998	-499	0	36	3	0.3	22	-438
1999	-631	0	67	6	0.6	24	-534
2000	**-762**	**0**	**50**	**5**	**0.5**	**26**	**-681**
2001	-890	0	51	5	0.5	27	-806
2002	-985	0	40	4	0.4	29	-912
2003	-1092	0	32	3	0.3	30	-1027
2004	*-1204*	*0*	*39*	*4*	*0.4*	*32*	*-1128*
2005	***-1363***	***0***	***44***	***4***	***0.4***	***33***	***-1281***
2006	*-1543*	*0*	*34*	*3*	*0.3*	*34*	*-1471*
2007	*-1672*	*0*	*36*	*3*	*0.3*	*35*	*-1596*
2008	*-1753*	*0*	*37*	*3*	*0.3*	*36*	***-1675***
2009	*-1792*	*0*	*50*	*5*	*0.5*	*38*	***-1699***
2010	***-1843***	***0***	***60***	***5***	***0.6***	***39***	***-1738***
2011	*-1876*	*0*	*62*	*6*	*0.6*	*41*	***-1767***
2012	*-1903*	*0*	*59*	*5*	*0.5*	*42*	***-1797***
2013	*-1930*	*0*	*59*	*5*	*0.6*	*43*	*-1822*
2014	*-1952*	*0*	*63*	*6*	*0.6*	*44*	*-1839*
2015	***-1672***	***-191***	***67***	***6***	***0.6***	***45***	***-1554***
2016	*-1783*	*-79*	*63*	*6*	*0.6*	*46*	*-1667*
2017	*-1882*	*-24*	*58*	*5*	*0.5*	*47*	*-1771*
2018	*-1996*	*16*	*56*	*5*	*0.5*	*48*	*-1886*
2019	*-2109*	*42*	*61*	*6*	*0.6*	*49*	*-1994*
2020	***-1730***	***-222***	***68***	***6***	***0.6***	***50***	***-1605***

Table A4. 4 Removal of atmospheric carbon by post-1990 afforestation –Wales A: Mid emissions scenario, B: Low emission scenario, C: High emission scenario

A (Mid) Wales	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-4**	**0**	**9**	**1**	**0.1**	**1**	**7**
1991	-4	0	8	1	0.1	1	6
1992	-2	0	6	1	0.1	2	6
1993	-4	0	7	1	0.1	3	7
1994	-9	0	7	1	0.1	3	3
1995	**-15**	**0**	**9**	**1**	**0.1**	**4**	**0**
1996	-21	0	11	1	0.1	5	-5
1997	-28	0	9	1	0.1	5	-13
1998	-36	0	9	1	0.1	6	-20
1999	-44	0	17	2	0.2	6	-19
2000	**-51**	**0**	**13**	**1**	**0.1**	**6**	**-30**
2001	-55	0	13	1	0.1	7	-34
2002	-60	0	10	1	0.1	7	-41
2003	-67	0	8	1	0.1	8	-50
2004	*-74*	*0*	*10*	*1*	*0.1*	*8*	*-55*
2005	***-80***	***0***	***10***	***1***	***0.1***	***8***	***-60***
2006	*-84*	*0*	*7*	*1*	*0.1*	*9*	*-67*
2007	*-88*	*0*	*8*	*1*	*0.1*	*9*	*-70*
2008	*-91*	*0*	*7*	*1*	*0.1*	*9*	***-73***
2009	*-93*	*0*	*10*	*1*	*0.1*	*10*	***-73***
2010	***-98***	***0***	***12***	***1***	***0.1***	***10***	***-75***
2011	*-102*	*0*	*12*	*1*	*0.1*	*10*	***-78***
2012	*-106*	*0*	*11*	*1*	*0.1*	*10*	***-83***
2013	*-110*	*0*	*11*	*1*	*0.1*	*10*	*-88*
2014	*-114*	*0*	*11*	*1*	*0.1*	*11*	*-91*
2015	***-109***	***-6***	***12***	***1***	***0.1***	***11***	***-85***
2016	*-117*	*-2*	*10*	*1*	*0.1*	*11*	*-95*
2017	*-126*	*1*	*9*	*1*	*0.1*	*11*	*-105*
2018	*-134*	*2*	*7*	*1*	*0.1*	*11*	*-115*
2019	*-140*	*1*	*8*	*1*	*0.1*	*12*	*-119*
2020	***-134***	***-7***	***10***	***1***	***0.1***	***12***	***-112***

B (Low) Wales	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
1990	**-4**	**0**	**9**	**1**	**0.1**	**1**	**7**
1991	-4	0	8	1	0.1	1	6
1992	-2	0	6	1	0.1	2	6
1993	-4	0	7	1	0.1	3	7
1994	-9	0	7	1	0.1	3	3
1995	**-15**	**0**	**9**	**1**	**0.1**	**4**	**0**
1996	-21	0	11	1	0.1	5	-5
1997	-28	0	9	1	0.1	5	-13
1998	-36	0	9	1	0.1	6	-20
1999	-44	0	17	2	0.2	6	-19
2000	**-51**	**0**	**13**	**1**	**0.1**	**6**	**-30**
2001	-55	0	13	1	0.1	7	-34
2002	-60	0	10	1	0.1	7	-41
2003	-67	0	8	1	0.1	8	-50
2004	*-75*	*0*	*9*	*1*	*0.1*	*8*	*-57*
2005	***-81***	***0***	***9***	***1***	***0.1***	***8***	***-63***
2006	*-85*	*0*	*6*	*1*	*0.1*	*9*	*-70*
2007	*-90*	*0*	*6*	*1*	*0.1*	*9*	*-75*
2008	*-96*	*0*	*5*	*0*	*0.0*	*9*	***-81***
2009	*-103*	*0*	*8*	*1*	*0.1*	*9*	***-86***
2010	***-113***	***0***	***9***	***1***	***0.1***	***9***	***-94***
2011	*-124*	*0*	*9*	*1*	*0.1*	*9*	***-105***
2012	*-134*	*0*	*7*	*1*	*0.1*	*10*	***-117***
2013	*-144*	*0*	*6*	*1*	*0.1*	*10*	*-128*
2014	*-154*	*0*	*6*	*1*	*0.1*	*10*	*-137*
2015	***-154***	***-6***	***6***	***1***	***0.1***	***10***	***-137***
2016	*-167*	*-2*	*4*	*0*	*0.0*	*10*	*-152*
2017	*-180*	*1*	*2*	*0*	*0.0*	*10*	*-168*
2018	*-193*	*2*	*1*	*0*	*0.0*	*10*	*-182*
2019	*-203*	*1*	*1*	*0*	*0.0*	*10*	*-192*
2020	***-202***	***-7***	***2***	***0***	***0.0***	***10***	***-190***

C (High) Wales	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO2**	**Afforestation + Deforestation**
1990	**-4**	**0**	**9**	**0**	**0.8**	**1**	**7**
1991	-4	0	8	0	1.5	1	6
1992	-2	0	6	0	2.2	1	6
1993	-4	0	7	0	2.8	1	7
1994	-9	0	7	0	3.4	1	3
1995	**-15**	**0**	**9**	**0**	**4.0**	**1**	**0**
1996	-21	0	11	0	4.6	1	-5
1997	-28	0	9	0	5.1	1	-13
1998	-36	0	9	0	5.6	1	-20
1999	-44	0	17	0	6.0	2	-19
2000	**-51**	**0**	**13**	**0**	**6.5**	**1**	**-30**
2001	-55	0	13	0	6.9	1	-34
2002	-60	0	10	0	7.3	1	-41
2003	-67	0	8	0	7.6	1	-50
2004	*-72*	*0*	*10*	*0*	*8.0*	*1*	*-53*
2005	***-78***	***0***	***11***	***0***	***8.4***	***1***	***-58***
2006	*-83*	*0*	*9*	*0*	*8.7*	*1*	*-65*
2007	*-86*	*0*	*9*	*0*	*8.9*	*1*	*-67*
2008	*-87*	*0*	*9*	*0*	*9.2*	*1*	***-67***
2009	*-86*	*0*	*13*	*0*	*9.5*	*1*	***-62***
2010	***-86***	***0***	***15***	***0***	***9.9***	***1***	***-59***
2011	*-85*	*0*	*16*	*0*	*10.2*	*1*	***-57***
2012	*-84*	*0*	*15*	*0*	*10.5*	*1*	***-57***
2013	*-83*	*0*	*15*	*0*	*10.8*	*1*	*-56*
2014	*-83*	*0*	*16*	*0*	*11.1*	*1*	*-55*
2015	***-74***	***-6***	***17***	***0***	***11.4***	***2***	***-44***
2016	*-79*	*-2*	*16*	*0*	*11.7*	*1*	*-50*
2017	*-84*	*1*	*15*	*0*	*11.9*	*1*	*-56*
2018	*-89*	*2*	*14*	*0*	*12.1*	*1*	*-61*
2019	*-91*	*1*	*15*	*0*	*12.3*	*1*	*-62*
2020	***-82***	***-7***	***17***	***0***	***12.5***	***2***	***-50***

Table A4. 5 Removal of atmospheric carbon by post-1990 afforestation –N. Ireland A: Mid emissions scenario, B: Low emission scenario, C: High emission scenario

A (Mid) N. Ireland	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-6**	**0**	**0**	**0**	**0.0**	**0**	**-6**
1991	-8	0	0	0	0.0	0	-8
1992	4	0	0	0	0.0	0	4
1993	11	0	0	0	0.0	0	11
1994	3	0	0	0	0.0	0	3
1995	**-8**	**0**	**0**	**0**	**0.0**	**0**	**-8**
1996	-17	0	0	0	0.0	0	-17
1997	-35	0	0	0	0.0	0	-35
1998	-52	0	0	0	0.0	0	-52
1999	-68	0	0	0	0.0	0	-68
2000	**-85**	**0**	**0**	**0**	**0.0**	**0**	**-85**
2001	-96	0	0	0	0.0	0	-96
2002	-105	0	0	0	0.0	0	-105
2003	-114	0	0	0	0.0	0	-114
2004	*-122*	*0*	*0*	*0*	*0.0*	*0*	*-122*
2005	***-131***	***0***	***0***	***0***	***0.0***	***0***	***-131***
2006	*-139*	*0*	*0*	*0*	*0.0*	*0*	*-139*
2007	*-148*	*0*	*0*	*0*	*0.0*	*0*	*-148*
2008	*-160*	*0*	*0*	*0*	*0.0*	*0*	***-160***
2009	*-173*	*0*	*0*	*0*	*0.0*	*0*	***-173***
2010	***-185***	***0***	***0***	***0***	***0.0***	***0***	***-185***
2011	*-195*	*0*	*0*	*0*	*0.0*	*0*	***-195***
2012	*-207*	*0*	*0*	*0*	*0.0*	*0*	***-207***
2013	*-199*	*-11*	*0*	*0*	*0.0*	*0*	*-199*
2014	*-192*	*-16*	*0*	*0*	*0.0*	*0*	*-192*
2015	***-215***	***-4***	***0***	***0***	***0.0***	***0***	***-215***
2016	*-234*	*2*	*0*	*0*	*0.0*	*0*	*-234*
2017	*-234*	*-5*	*0*	*0*	*0.0*	*0*	*-234*
2018	*-231*	*-11*	*0*	*0*	*0.0*	*0*	*-231*
2019	*-236*	*-10*	*0*	*0*	*0.0*	*0*	*-236*
2020	***-248***	***-6***	***0***	***0***	***0.0***	***0***	***-248***

B (Low) N. Ireland	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	**-6**	**0**	**0**	**0**	**0.0**	**0**	**-6**
1991	-8	0	0	0	0.0	0	-8
1992	4	0	0	0	0.0	0	4
1993	11	0	0	0	0.0	0	11
1994	3	0	0	0	0.0	0	3
1995	**-8**	**0**	**0**	**0**	**0.0**	**0**	**-8**
1996	-17	0	0	0	0.0	0	-17
1997	-35	0	0	0	0.0	0	-35
1998	-52	0	0	0	0.0	0	-52
1999	-68	0	0	0	0.0	0	-68
2000	**-85**	**0**	**0**	**0**	**0.0**	**0**	**-85**
2001	-96	0	0	0	0.0	0	-96
2002	-105	0	0	0	0.0	0	-105
2003	-114	0	0	0	0.0	0	-114
2004	*-126*	*0*	*0*	*0*	*0.0*	*0*	*-126*
2005	***-131***	***0***	***0***	***0***	***0.0***	***0***	***-131***
2006	*-132*	*0*	*0*	*0*	*0.0*	*0*	*-132*
2007	*-138*	*0*	*0*	*0*	*0.0*	*0*	*-138*
2008	*-150*	*0*	*0*	*0*	*0.0*	*0*	***-150***
2009	*-169*	*0*	*0*	*0*	*0.0*	*0*	***-169***
2010	***-190***	***0***	***0***	***0***	***0.0***	***0***	***-190***
2011	*-212*	*0*	*0*	*0*	*0.0*	*0*	***-212***
2012	*-234*	*0*	*0*	*0*	*0.0*	*0*	***-234***
2013	*-236*	*-11*	*0*	*0*	*0.0*	*0*	*-236*
2014	*-240*	*-16*	*0*	*0*	*0.0*	*0*	*-240*
2015	***-272***	***-4***	***0***	***0***	***0.0***	***0***	***-272***
2016	*-301*	*2*	*0*	*0*	*0.0*	*0*	*-301*
2017	*-309*	*-5*	*0*	*0*	*0.0*	*0*	*-309*
2018	*-315*	*-11*	*0*	*0*	*0.0*	*0*	*-315*
2019	*-329*	*-10*	*0*	*0*	*0.0*	*0*	*-329*
2020	***-350***	***-6***	***0***	***0***	***0.0***	***0***	***-350***

C (High) N. Ireland	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
1990	**-6**	**0**	**0**	**0**	**0.0**	**0**	**-6**
1991	-8	0	0	0	0.0	0	-8
1992	4	0	0	0	0.0	0	4
1993	11	0	0	0	0.0	0	11
1994	3	0	0	0	0.0	0	3
1995	**-8**	**0**	**0**	**0**	**0.0**	**0**	**-8**
1996	-17	0	0	0	0.0	0	-17
1997	-35	0	0	0	0.0	0	-35
1998	-52	0	0	0	0.0	0	-52
1999	-68	0	0	0	0.0	0	-68
2000	**-85**	**0**	**0**	**0**	**0.0**	**0**	**-85**
2001	-96	0	0	0	0.0	0	-96
2002	-105	0	0	0	0.0	0	-105
2003	-114	0	0	0	0.0	0	-114
2004	*-119*	*0*	*0*	*0*	*0.0*	*0*	*-119*
2005	***-130***	***0***	***0***	***0***	***0.0***	***0***	***-130***
2006	*-145*	*0*	*0*	*0*	*0.0*	*0*	*-145*
2007	*-157*	*0*	*0*	*0*	*0.0*	*0*	*-157*
2008	*-167*	*0*	*0*	*0*	*0.0*	*0*	***-167***
2009	*-175*	*0*	*0*	*0*	*0.0*	*0*	***-175***
2010	***-180***	***0***	***0***	***0***	***0.0***	***0***	***-180***
2011	*-182*	*0*	*0*	*0*	*0.0*	*0*	***-182***
2012	*-186*	*0*	*0*	*0*	*0.0*	*0*	***-186***
2013	*-170*	*-11*	*0*	*0*	*0.0*	*0*	*-170*
2014	*-155*	*-16*	*0*	*0*	*0.0*	*0*	*-155*
2015	***-171***	***-4***	***0***	***0***	***0.0***	***0***	***-171***
2016	*-183*	*2*	*0*	*0*	*0.0*	*0*	*-183*
2017	*-177*	*-5*	*0*	*0*	*0.0*	*0*	*-177*
2018	*-166*	*-11*	*0*	*0*	*0.0*	*0*	*-166*
2019	*-164*	*-10*	*0*	*0*	*0.0*	*0*	*-164*
2020	***-169***	***-6***	***0***	***0***	***0.0***	***0***	***-169***

Section 3

The influence of land use change from and to forestry on the emissions of nitrous oxide and methane

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3. The influence of land use change from and to forestry on the emissions of nitrous oxide and methane

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3.1. Introduction and background

Compared to the data available on nitrous oxide (N_2O) and methane (CH_4) emissions from agricultural or forest soils, there are only little information on the effect of land use change from and to forestry on the emissions of N_2O and CH_4. Predictions of N_2O and CH_4 release due to land use change are therefore calculated from existing general knowledge (mainly from agricultural soils) of the production and emission of these gases in relation to different soil types and climatic conditions.

Nitrous oxide and CH_4 are products of microbial processes in the soil. In general N_2O production increases with increasing concentrations of ammonium and nitrate, available organic C (carbon) content and with increasing soil wetness and soil density (Skiba & Smith, 2000). However, when the soil becomes too wet, N_2O is further reduced to N_2, therefore N_2O emissions decrease (Davidson, 1991).

The net CH_4 emission from a soil is influenced by the activity of two microbial communities, the methanogens and CH_4 oxidisers. Methane production requires strict anaerobic conditions and in the UK the wettest parts of moorlands are the largest source of $CH_{4,}$ but even the contribution of these to the total national emission is less than 5%. Occasionally grassland soils can be a temporary and small source of CH_4. Most of the CH_4 produced in the deeper anaerobic layers of a soil by the methanogens are oxidised by the methane oxidisers in the aerated upper parts of the same soil. Methane oxidisers are very sensitive to soil disturbance by physical means, for example ploughing and compaction, or chemical disturbance, mainly N fertilisation (MacDonald *et al.*, 1997).

Because of the lack of data on N_2O and CH_4 emissions caused by land use change, only the IPCC default methodology was applied.

3.2. Nitrous oxide emissions

3.2.1. Forest land remaining forests

The direct emissions of N_2O from forests remaining forest (IPCC good practice guidance for LULUCF equation 3.2.17) are calculated from the sum of organic and inorganic N fertiliser induced N_2O and the N_2O emitted due to drainage. *(from now on the IPCC good practice guidance for LULUCF will be referred to as: IPCC)*

N fertiliser: For the N fertiliser induced N_2O emission the standard EF1 (1.25% of N applied is emitted as N_2O) is applied. Normally only newly planted forests are fertilised at a rate of 150 kg N h^{-1}, the resulting N_2O emissions are shown in Table 3-1. The uncertainty range of emission factor EF_1 (0.25 to 6%) suggests that newly planted forests in the UK emit 0.06 to 117 t N_2O-N y^{-1}.

Drainage: The effect of drainage is dealt with by default emission rates based on very few data from Scandinavian countries (Appendix 3.a.2 Table 3a.2.1).

The influence of drainage on N_2O emissions is based on many assumptions, as data on drainage and fertility status of the UK forest soils are not readily available. Drainage induced N_2O

emissions were therefore calculated based on the assumption that 50 % of the organic soils are nutrient rich and 50% are nutrient poor and that in Britain 25% of forest grown on mineral soils and 50% of forests grown on organic soils are drained. For Northern Ireland it was assumed that 50% of all forests are drained. The default emissions of 0.1 and 0.6 kg N_2O-N ha^{-1} y^{-1} for nutrient poor and nutrient rich organic soils, and of 0.06 kg N_2O-N ha^{-1} y^{-1} for mineral soils were applied (IPCC Appendix 3.a.2 Table 3a.2.1) (Table 3-2). The drainage related emission rates carry large uncertainties, both in forest areas subjected to this practice and in the actual emission rates. This management practice 'drainage' influences N_2O emissions more than N application to newly planted forests.

Table 3-1 Direct N_2O emissions from newly planted forests

	Established forest	**New Forest***	**N fertiliser applied to new forest**	**N_2O emission from new forests⁺**
	*1000ha	*1000ha	Kg N y^{-1}	t N y^{-1}
England	1104.69	5.31	796500	9.96
Wales	285.67	0.33	49500	0.62
Scotland	1320.27	6.73	1009500	12.62
N Ireland	80.4	0.59	88500	1.11
UK	2791.03	12.96	1944000	24.30

* planted 2002 – 2003, $^+$ EF_1

Table 3-2 The influence of drainage on N_2O emissions from existing forests

	Soil type		**N_2O emission**		
	Organic	**Mineral**	**Organic**	**Mineral**	**All soils**
	*1000 ha		t N_2O-N y^{-1}		
England	200.7	177.4	60.2	10.6	70.8
Wales	43.3	49.9	13.0	3.0	16.0
Scotland	286.5	188.5	86.0	11.3	97.3
N Ireland	20.1	20.1	6.0	1.2	7.2
UK	550.5	435.9	165.2	26.2	191.3

Indirect emissions due to atmospheric N deposition: Atmospheric depositions of N to forests soils are a much larger source of N_2O from established forests than mineral N fertiliser application and drainage induced emissions. The IPCC default emission factor for N deposition induced N_2O emissions is 1 and here was applied to soils with an organic matter content of >25.5%. For mineral soils (OM < 25.5%) the IPCC default emission factor was replaced by a linear regression equation ($N_2O\text{-}N_{(kgN/ha/y)} = 0.0006 * Ndep^2_{(kgN/ha/y)} + 0.0032 * N\ dep_{(kgN/ha/y)}$) based on CEH's data from forest and moorland soils in Britain. The atmospheric N deposition induced N_2O emission for UK forests was calculated at 0.9 kt N_2O-N y^{-1}, which is not included in the current inventory.

3.2.2. Land converted to forest

Agricultural land or moorland converted to forests may require some N_2O releasing activities, such as ploughing of grassland, drainage of wetlands, fertilisation and irrigation of the freshly planted trees. Drainage and ploughing will increase N_2O emission; unfortunately real data are very limited. If we assume that all trees on land converted to forests are fertilised at a rate of 150 kg N ha^{-1} d^{-1}, then this activity will not alter previous emission rates. However, if the land was converted from moorland or unmanaged wasteland then emissions will increase.

None of these activities are likely to increase N_2O emissions significantly. For example, if the existing forest area is increased by 50 %, and is fertilised at a rate of 150 kg N ha^{-1} y^{-1} and 50% is drained (as shown in section 3.2.1), then this activity will increase N_2O emissions by 2.7 kt N_2O-N y^{-1}, (2.6 kt are fertiliser induced emissions and 0.1 kt are drainage induced emissions). This exaggerated increase remains to be a small fraction of the total agricultural N_2O emissions of 86 kt N_2O-N (Skiba et al, 2005).

3.2.3. Land (forests) converted to cropland

Forest land converted to cropland requires clear felling, ploughing and perhaps drainage. All these activities will stimulate nitrogen mineralization of the organic matter.

In the first instance there will be no competition for this available nitrogen between plants and microbes, thereby maximising substrate availability for microbial nitrification and denitrification to occur and release N_2O. This initial surge in mineralisation rate and increase in N_2O emissions is a short-term effect (max 1 year). Unfortunately most of deforestation related greenhouse gas studies have concentrated on tropical forests; data from northern Europe are restricted to a few studies (eg. Emmett & Quarmby, 1991), therefore it is not possible to change the default methodology. It is assumed that the same emission factor EF1 (1.25%) used for N fertilised soils applies to nitrogen released by organic mineralization, which is calculated from the annual change in C stock (equation 3.3.12) divided by the C/N ratio (equation 3.3.15). Based on these equations and assuming a C/N ratio of 15 it was calculated that forest land converted to crops was responsible for an annual N_2O emission of 2.8 kt N_2O-N in 2002, which is 2.3% of the total UK N_2O emission budget. This emission rate did not change by more than 0.1 kt N_2O-N y^{-1} when applied to data of forest conversion to cropland over a 50-year period. (Figure 3-1).

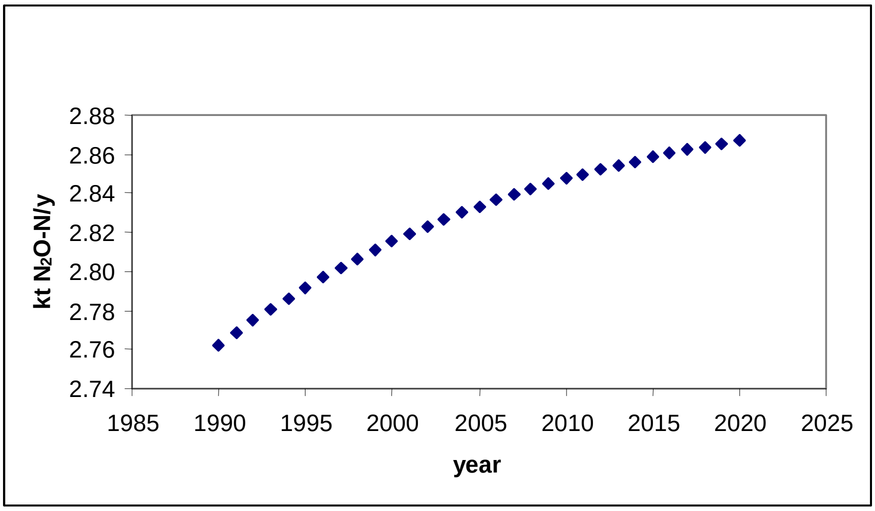

Figure 3-1 Nitrous oxide emissions from the mineralization of organic matter during land conversion from forests to crops in the UK (equation 3.3.15).

Land converted to grassland:

This activity will require N fertilisation and ploughing and in some circumstances drainage. Therefore N_2O emissions are likely to increase. The drainage, ploughing and fertiliser emission factors to be used remain the IPCC default emission factors, as there is not enough UK data or data from similar temperate climates. Generally grasslands tend to be larger sources of N_2O than arable soils or forests, due to larger mineralization rates and prevalence of grasslands in the wetter parts of the country. At present one can assume zero conversion from forest to grassland and hence zero source of N_2O and CH_4.

Land converted to wetlands:

The total area in the UK converted to wetlands is restricted to small insignificant areas of newly created riparian zones, along rivers in nitrogen vulnerable zones (NVZ). This activity has a potential to decrease N_2O emissions, if the soil water filled pore space (WFPS) can be maintained above 90% (Skiba & Smith, 2000). Under such conditions anaerobic conditions and accumulation of soil organic matter content will favour denitrification to proceed to N_2 rather than stop at N_2O production which is generally the case in more aerobic soils.

3.3. Methane emissions

In the UK soils contribute only 120 kt CH_4 y^{-1}, which is less than 6% of the total UK CH_4 budget. Therefore any landuse change will not significantly influence this budget.

3.3.1. Forest land remaining forests

Undisturbed forest soils are an important source of CH_4 oxidation. For European forests it was estimated that CH_4 is oxidised at a rate of 2.4 or 4.5 kg CH $ha^{-1}y^{-1}$ (Smith *et al.*, 2000 and van Cleemput *et al.*, 2000). Based on these oxidation rate established UK forests oxidise 9 kt CH_4 y^{-1}, which accounts for a small fraction of the total UK CH_4 emission (2228 kt CH_4 y^{-1}in 2002). Methane oxidation rates are affected by disturbance, such as land use change, drainage, ploughing and N fertiliser application (Prieme *et al.*, 1997, MacDonald *et al.*, 1997). Therefore any landuse change will reduce the CH_4 oxidising capacity of the forests.

Only very occasionally during wet soil conditions does the forest soil temporarily turns into a very small net source of CH_4.

3.3.2. Land converted to forest

Increasing the land area of forests will eventually increase the CH_4 oxidation capacity of the soil. If the previous landuse was undrained moorland the effect will be largest, and will slowly turn a net CH_4 source into a CH_4 sink (Prieme *et al.*, 1997). Again the influence on the UK CH_4 budget will be insignificant.

3.3.3. Land (forests) converted to cropland or grassland

These activities will reduce the CH_4 sink activity of forests, by disturbance and N fertilisation.

Land converted to wetlands:

Methane emissions will increase when land is converted to wetland. However, soils contribute to only a small fraction of the UK CH_4 budget, and an increase in this activity is unlikely to change this.

3.4. Conclusions

Landuse change to and from forestry will not provide a significant source of the greenhouse gases N_2O or CH_4 as shown in Table 3-3.

Table 3-3 The influence of landuse change on N_2O and CH_4 emissions. Emissions are expressed as a percentage of the UK agricultural N_2O emissions (86 kt N_2O- N y^{-1}) and wetland CH_4 flux (120 kt CH_4 y^{-1}).

	Forest-forest	Forest - crop	Forest - grass	Forest - moorland	Other land to forests
Nitrous oxide (kt N_2O-N y^{-1})	0.23 %	3.3 %	3.3 %	0 & uptake	3.1 %
Methane (kt CH_4 $y^{-1-)}$	-7.5% oxidation	0	0	7.5 emission	-7.5 % (after 2 0+ years) oxidation

3.5. References

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Section 4

Carbon Stock Changes due to Harvested Wood Products in the UK

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4. Carbon Stock Changes due to Harvested Wood Products: UK

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June 2005

4.1. Key Results

- The EXPHWP spreadsheet model will be useful in calculating carbon flows due to harvested wood products (HWP) in the UK.
- The model provides three methods of calculating carbon flows due to HWP: the Stock-Change Approach, the Atmospheric-Flow Approach and the Production Approach.
- The model uses forestry data from FAOSTAT that is of high quality and regularly updated
- Estimates of the domestic component in HWP production in the Production Approach can be improved
- Results from the EXPHWP model are comparable with those previously produced by CEH using the C-Flow model

4.2. Introduction

Carbon stock changes due to Harvested Wood products (HWP) in the UK were calculated with the aid of the EXPHWP spreadsheet provided by Kim Pingoud of the Finnish Forest Research Institute. The EXPHWP model uses data from the FAO forestry database (FAOSTAT, 2005) and parameters provided by the user. The carbon stock flows for the three HWP accounting approaches with the original version of the spreadsheet are shown in Figure 4-1. The Stock-Change Approach reports the carbon stock changes in HWP in use (consumed) in the UK: a positive stock change is a carbon removal due to HWP. The Atmospheric-Flow Approach reports the carbon emission by decaying HWP, which will then be added to the carbon uptake from growing forest biomass. This carbon emission is estimated from the stock change of HWP in use + Exports of HWP – Imports of HWP. The Production Approach is similar to the Stock-Change Approach but also considers the fate of exported wood products.

The EXPHWP model does not currently calculate carbon stocks in solid waste disposal sites (SWDS). Nor does it consider the international trade in finished wood products (e.g. furniture, books, etc.), as these statistics are not available from the FAO database.

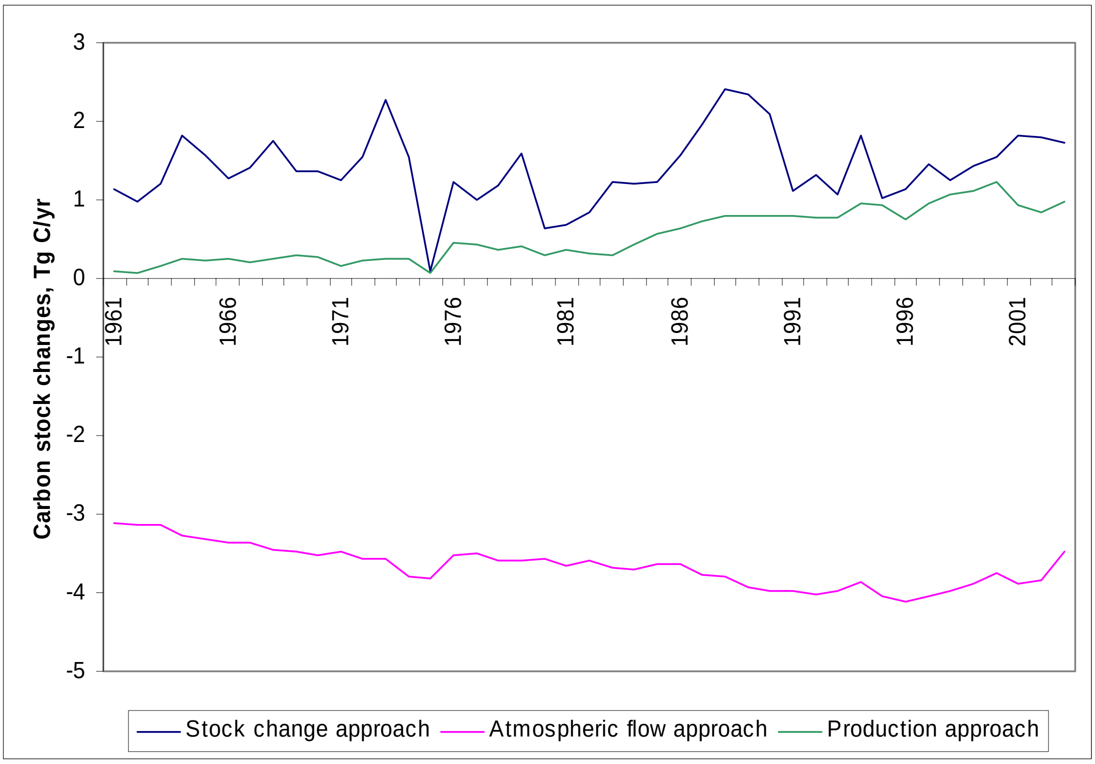

Figure 4-1: Comparison of HWP accounting approaches for the UK using the original values in the EXPHWP model

4.3. Potential model modifications

4.3.1. Input parameters

The current version of the spreadsheet model allows the user to adjust several input parameters: half-lives of wood products, conversion factors for carbon content and growth in HWP consumption prior to 1961.

4.3.1.(a) Half-lives of products

The effect of assumptions on half-life were investigated by making adjustments to the basis of the mix of HWP in 2003 and the half-lives for individual products given by the IPCC defaults ((IPCC, 2003), p.3.270)) and Pingoud *et al* (1996). From this method, the half-life of solid wood products has declined over time from 34.15 years in 1961. Small changes to half-life values appeared to have little impact on the carbon stock outputs so a case could be made for retaining the original model inputs.

Half-life, years	Original values	Adjusted values
Solid wood products	30.00	30.25
Paper and paperboard	1.00	1.32

4.3.1.(b) Conversion factors from volume (m^3) to carbon content (Mg)

The conversion factors were adjusted on the basis of the mix of different products in each HWP category in 2003 and the IPCC default conversion factors (IPCC 2003, p.3.265). This adjustment did not have a great impact on the carbon stock outputs. The model input of 1.35% growth rate of HWP consumption prior to 1961 was retained.

	Original values	Adjusted values
Sawnwood	0.225	0.229
Wood-based panels	0.294	0.248
Paper	0.45	0.45

4.3.2. Data input

Data used in the EXPHWP model has been taken from the FAO forestry database (FAOSTAT 2005). This was provided by the UK Expert Group on Timber and Trade Statistics and appears to be the best available complete dataset. The recent UK production statistics are also UK National Statistics (a hall mark of data quality), but statistics for years before 1994 and for imports and exports have not undergone the same quality assurance procedures (although they are still the best available). A recent release of UK Wood Production and Trade figures (May 2005, http://www.forestry.gov.uk/pdf/trprod05.pdf/$FILE/trprod05.pdf) gives revised values for 2003 and 2004 that have not yet been included in the FAO database. These revised values were used in place of the original values in the EXPHWP model.

4.3.3. Adjustment to the production approach calculations

In the Production Approach the domestic production of solid wood and paper products is multiplied by the fraction (domestic roundwood production / roundwood consumption) to give an estimate of how much of the manufactured HWP are made from timber of domestic origin. Consumption is calculated as (production + imports – exports). Due to exports, the domestic production fraction can exceed 1.00, which is misleading as only (roundwood production – roundwood exports) is actually available for HWP manufacture. Therefore, the multiplier fraction is given by (round wood production / (production + imports)). This generates slightly lower values of carbon stock change in the EXPHWP model (Figure 4-2) and slight changes in the total carbon stock (Figure 4-3). It should be noted that wood fuel is included in roundwood production, although strictly speaking wood fuel is carbon-neutral because there is no long-term carbon storage (Nabuurs et al., 2001).

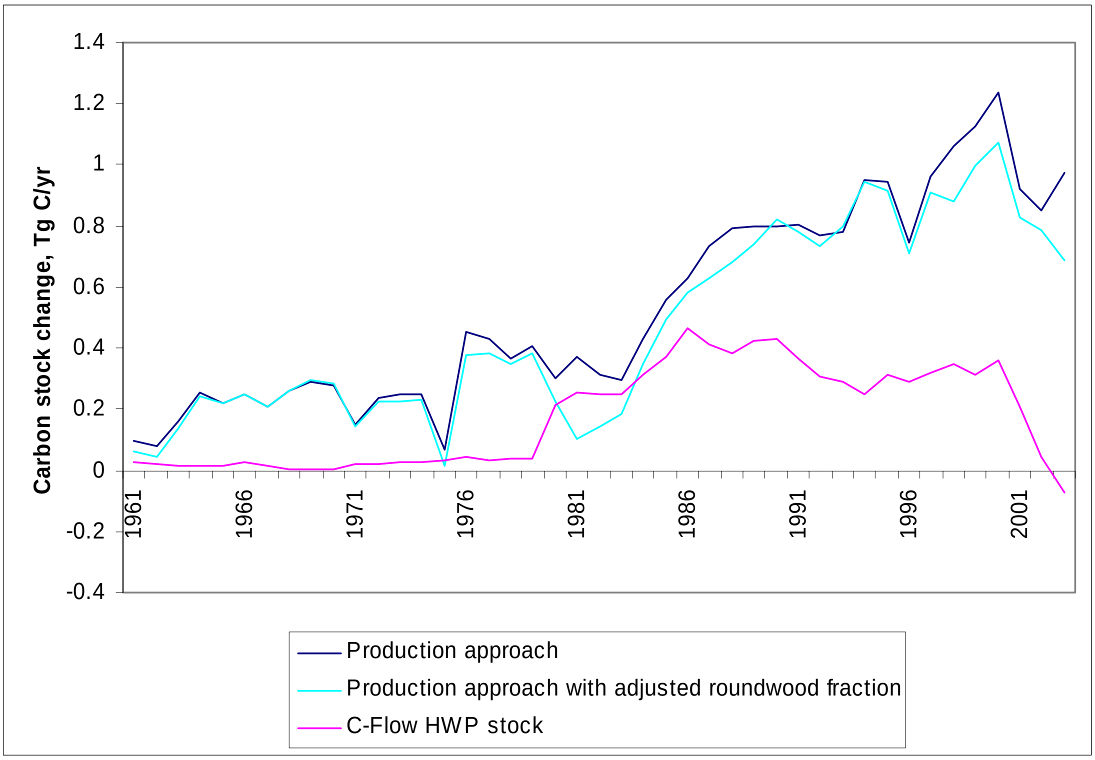

Figure 4-2: Comparison of HWP carbon stock changes estimated by the original EXPHWP model, the modified EXPHWP model and the C-Flow model

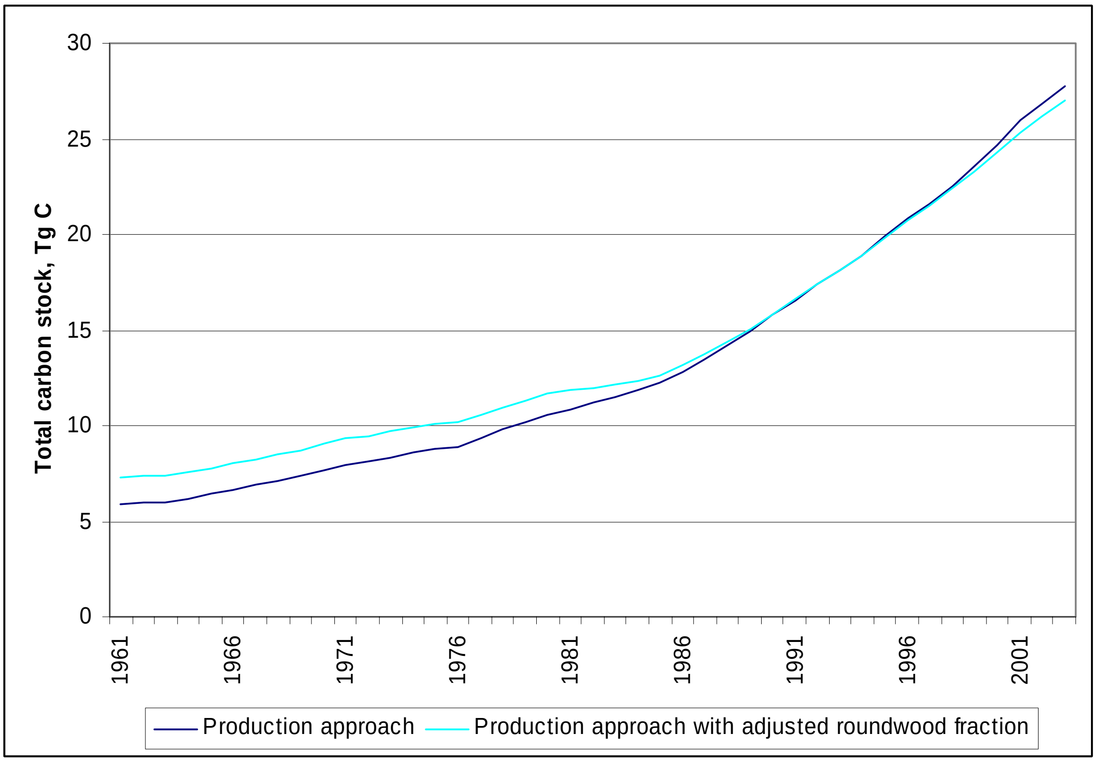

Figure 4-3: Comparison of the total HWP carbon stock estimated by the original and modified EXPHWP model.

4.4. Comparison with C-Flow product estimates

Previous estimates of carbon stock changes in the UK due to HWP have been produced by CEH using the C-Flow model (Baggott et al., 2004). This operates in a similar manner to the Production Approach, but only estimates production from forests planted since 1922, excluding approximately 850,000 hectares of woodland that were either planted before this date or are not of commercial importance. The C-Flow model also assumes a longer lifespan for harvested wood products, equal to the rotation length of the forest.

Figure 4-2 shows HWP carbon stock changes from C-Flow compared to those from the EXPHWP model production approach (both original and modified). Some of the differences between the models can be explained because C-Flow is based on planting data so HWP only become available after a time lag of 60 years (equal in length to a softwood rotation) (see Figure 4-4). Both models predict the drop in domestic HWP production after 2000 due to the drop in new planting during World War II.

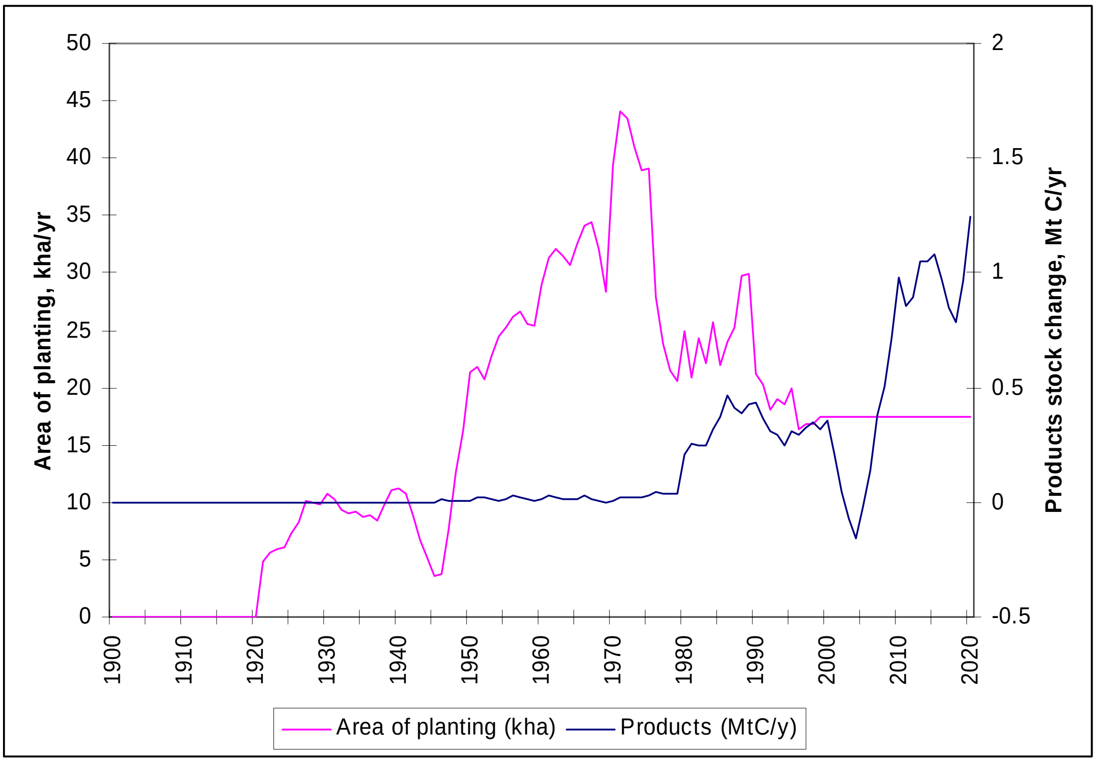

Figure 4-4: Comparison of C-Flow estimated planting and HWP stocks over time in the UK

4.5. Summary

In general, the EXPHWP model seems useful for the calculation of carbon flows due to harvested wood products. The data used in the model (from FAOSTAT) appears to be the best available for the UK but may be subject to minor revisions. The calculation of the Production Approach could be improved by using a different ratio to estimate the amount of HWP that has been produced from roundwood of UK origin. Estimates of carbon stock changes due to HWP from the EXPHWP model were comparable with those from the C-Flow model (given the difference in the two approaches). The EXPHWP model does not currently calculate the HWP stocks in solid waste disposal sites, although this is being addressed. Neither does the model consider the import and export of finished wood products such as furniture, books and newspapers, or the production of wood for miscellaneous uses such as fencing (263,000 green tonnes in 2003 ((Forestry-Statistics, 2004)).

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Section 5

Mapping of carbon emissions and removals in the UK due to changes in stocks of soil carbon driven by land use change other than afforestation

(Funded as part of AEAT Annual Inventory Contract – Agreement Number 1470663 CEH/AEAT)

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5. Mapping of carbon emissions and removals in the UK due to changes in stocks of soil carbon driven by land use change other than afforestation

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5.1. Introduction

5.1.1. Background

CEH (Edinburgh) annually prepares estimates of the uptake (removal from atmosphere) of carbon dioxide by afforestation and net loss or gain of carbon dioxide from soils (emissions to or removals from the atmosphere) for inclusion in the UK GHG Inventory. These estimates are made using dynamic models of change in stored carbon driven by land use change data. For forestry the model deals primarily with plant carbon and is driven by the area of land newly afforested each year. The changes in soil carbon are driven by estimated time series of land use transitions between semi-natural, cultivated (farm), woodland and urban. The models are run for each of the four devolved administrative regions of the UK and the data included in the annual national Greenhouse Gas Inventory. Until now no data has been reported in a map format.

In a previous contract between AEAT and CEH (Edinburgh) on mapping LUCF fluxes a disaggregation of removals for the three devolved regions of Great Britain was made for the plant carbon (afforestation) flux in 400 km^2 grid-cells for 1990 and 1995.

The work described here extends the LUCF mapping work by: i) preparing maps of net emissions in 1990 and other years from soils due to land use change in United Kingdom prior to that date.

Devolved region estimates of gains or losses of soil carbon due to land use change are estimated by CEH (Edinburgh) for the UK GHG Inventory using a model of change in soil carbon that follows an exponential pattern with time after a change in land use. The difference in mean soil carbon density between different land use for each devolved region is estimated and the rate of transition from one density to another is set for each type of transition between land use types. The land use change data is derived from transition matrices developed from Measuring Landscape Change (MLC), (see MLC, 1986) and Countryside Survey (CS) programmes carried out in 1947, 1980, 1984 and 1990 and summarised at the scale of the devolved regions.

Work has been undertaken in a separate project in CEH (Edinburgh) to build land use change matrices between 1990 and 1998 from the Land Cover Maps of Great Britain developed by ITE/CEH for those two years and the results could also be applied to disaggregating net emissions from soils. This work also showed that, although CS data on land use change at scales smaller than 10,000 km^2 had previously been considered to be unreliable, a good correlation with information from the land cover maps was achieved at much smaller scales.

Here we develop time series of land use change in 20 x 20 km grid-cells (to match those used for the afforestation fluxes) for the period from using the Countryside Surveys covering periods1984 to 1990 and 1990 to 1998. The land use change matrices for the 20 x 20 km grid-cells are scaled to match those used in estimates of emissions and removals for the devolved administration areas in the United Kingdom These matrices can then be used for each grid-cell in a model analogous to that presently used for the full devolved area.

5.2. Method

5.2.1. Dividing the UK into 20km by 20km grid squares

The basic resolution for mapping of emissions and removals has been set to the 1km by 1km squares covering Great Britain and the Isle of Man. There are a total of 240243 1km points. Land use change information from the Countryside Surveys would not be reliable at this scale. A grid of 20 km by 20 km was used for analysis of afforestation fluxes (Milne & Brown, 2003) and is used here for compatibility.

These 240243 1km points have been assigned to the 804 larger grid squares of 20km by 20km (see Figure 5-1). Each large square can contain between 1 and 400 1km points depending whether the region is entirely land or contains sea or other bodies of water. The centre of each circle in Figure 5-1 shows the location of the SW corner of a 20km square and the area of each circle indicates the amount of land (1km squares) enclosed by the larger square. Each 20km by 20km grid square is also assigned to England, Scotland or Wales according to the dominant country out of the 400 smaller points, as indicated by the colour of each point shown on the map. This approximation allocates 127887km^2 to England, 86983km^2 to Scotland and 24715km^2 to Wales. The Isle of Man accounts for 7 of the grid squares and these have been discarded, as no land use information is currently available. The axes in Figure 5-1 show the Easting and Northing coordinates of the National Grid used to identify each square.

Similarly, Northern Ireland contains 13466 1km squares that can be allocated to 55 20km by 20km squares (Figure 5-2). Note that the National Grid coordinate system for Northern Ireland is not the same as that used for Great Britain. The Easting and Northing coordinates shown in Figure 5-1 and Figure 5-2 cannot be used directly to plot the full UK data on one map without further calculations.

In total, there are 852 grid squares across the UK that will be used to map carbon flux due to land use change.

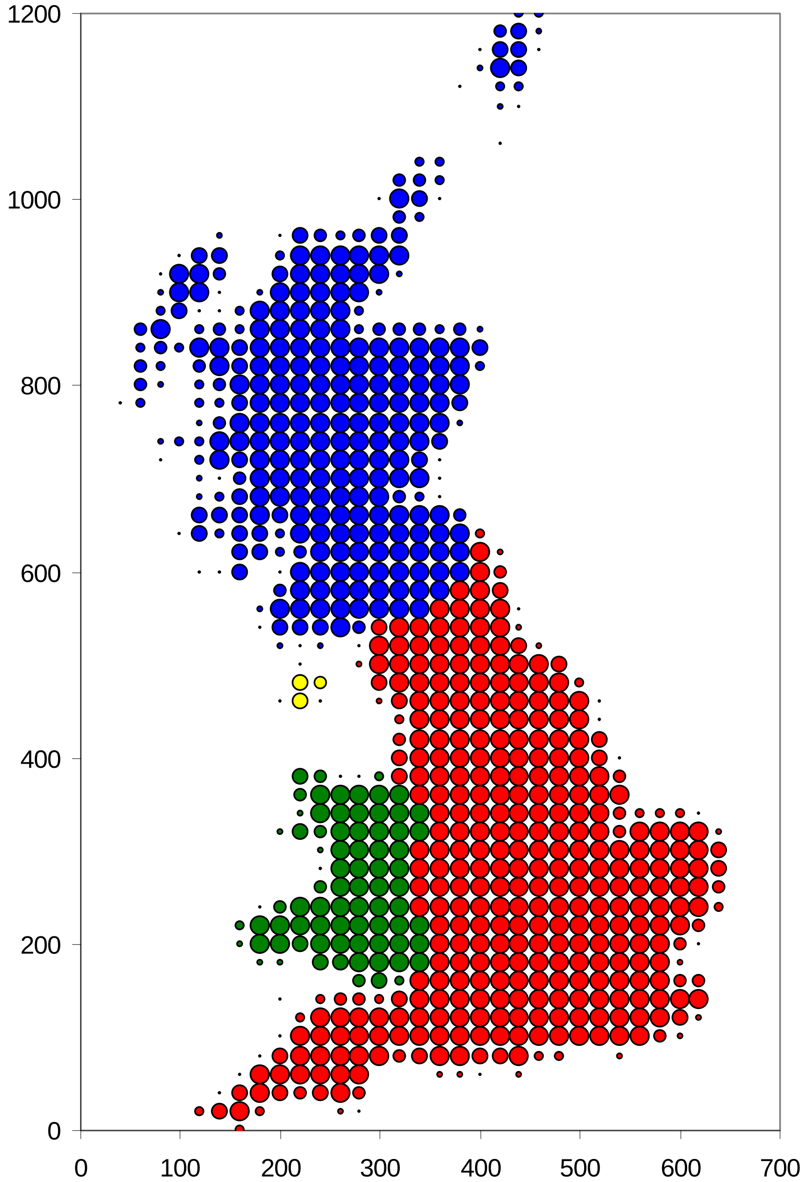


Figure 5-1: Scotland, England, Wales and the Isle of Man showing the location of the 804 20km by 20km grid squares. The relative size of each circle indicates the number of 1km points contained within the square (1 to 400).

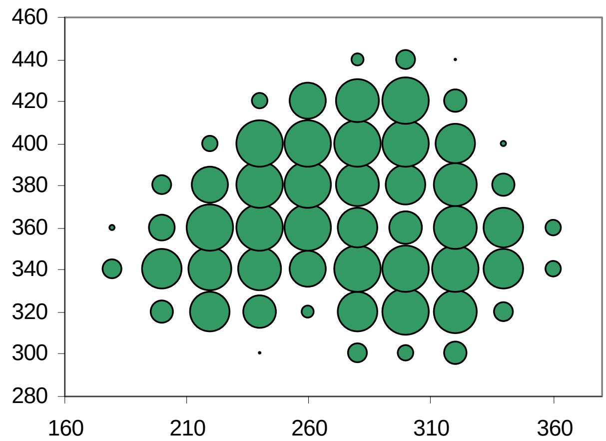


Figure 5-2: Northern Ireland showing the location of the 55 20km by 20km grid squares.

5.2.2. Land Use Change Matrices

For this exercise six basic land use types were used

- Woodland
- Natural
- Farm, Pasture (grassland)
- Farm, Arable (cropland)
- Urban
- Other

and the rate at which areas of land change from one use to another within these categories for the seven decades 1950's to 2010's. A typical land use change (LUC) matrix is shown in Table 5-1, in this example the data are 1000s ha change for England between 1950 and 1959. For this exercise we do not use data for land areas that do not change use within these categories.

Table 5-1: An example of a land use change matrix (England, 1950 to 1959). Data are 1000 ha.

From \ To	Woods	Natural	Farm (Pasture)	Farm (Arable)	Urban	Other
Woods		3.83	3.63	0.87	0.16	0.0
Natural	0.08		0.2	0.0	0.0	0.0
Farm (Pasture)	3.36	4.62		19.79	0.75	0.0
Farm (Arable)	2.01	0.95	51.34		1.34	0.0
Urban	0.51	0.12	10.15	5.96		0.0
Other	0.0	0.0	0.0	0.0	0.0	

The Countryside Survey contains information on land class for Great Britain on a 1km scale and sampled data relating land use change between 1984 and 1990 and between 1990 and 1998 to the land class. By querying this data we can draw up land use change matrices showing the total area of land changing from one use to another within each of the 797 squares (20 km by 20 km) of Great Britain, between the years given above.

The land use change matrix for the data 1984 to 1990 is assumed to be representative of the full decade 1980 to 1989, and the change of use of the land is assumed to be constant throughout the decade. Thus one sixth of the total change is assumed to take place for each year 1980 to 1989.

Similarly, the land use change matrix for the data 1990 to 1998 is assumed to be representative of the full decade 1990 to 1999, and the change of use of the land is assumed to be constant throughout the decade. Thus one eighth of the total change is assumed to take place for each year 1990 to 1999.

We assume that the land use change recorded between 1990 and 1999 also applies for years following 1999, thus the same rate of change is applied to each year in the decades 2000 to 2009 and 2010 to 2019.

For earlier decades 1950 to 1979, the land use change information is only available (from the Monitoring Landscape Change data) as country totals for England, Scotland and Wales. To disaggregate the land use change across the countries, we assume the pattern of change is uniform across the region and will therefore be distributed across 20km by 20km squares in proportion to the number of 1km land squares in each grid square (see Figure 5-1).

An adjustment is applied to the data for all decades to align the values for afforestation and deforestation with those reported by Forestry Commission and use in modeling of removals and emissions for these activities.

The Countryside Survey data does not cover Northern Ireland. For the 55 grid squares covering this region we use the full regional information, distributed in proportion to the number of $1km^2$ land squares as shown in Figure 5-2. See Chapter 2 Section 2.2.3 for further information on sources of data for Northern Ireland.

5.2.3. Calculating the Carbon flux

Each change of land use results in an exchange of carbon with the atmosphere. This may be due to changes in the soil as well as changes in the type of vegetation that defines the land type.

Milne (Chapter 2, Section 2.2.3 of this report) describes the method used to calculate the total carbon flux associated with each of the 30 possible land use changes, previously applied at the national scale. The convergence rates and C change for each land use change for each country calculated by Milne are applied at the 20km x 20km scale. Table 5-2 gives typical values for a C change matrix.

Table 5-2: An example of the estimated C change (England).

From \ *To*	*Woods*	*Natural*	*Farm (Pasture)*	*Farm (Arable)*	*Urban*	*Other*
Woods		24.6	24.6	32.0	83.5	0.0
Natural	-21.2		0.0	22.8	78.6	0.0
Farm (Pasture)	-21.2	0.0		22.8	78.6	0.0
Farm (Arable)	-31.2	-23.0	-23.0		52.3	0.0
Urban	-87.0	-76.1	-76.1	-53.6		0.0
Other	0.0	0.0	0.0	0.0	0.0	

5.2.3.(a) Midpoint estimates

For each of the 852 grid squares across the UK the main calculations, for each year from 1990 onwards, give

1. 'Old flux' - Flux of carbon due to land use changes between 1950 and 1979
2. 'New flux' – Flux of carbon from due to land use changes between 1980 to 2020
3. 'ToGrass' - the total C flux (old and new) associated with changes to grassland (natural + farm pasture).
4. 'To Crop' - the total C flux (old and new) associated with changes to cropland (farm arable).
5. 'To Settle' - the total C flux (old and new) associated with changes to urban (settlements).
6. 'To Other' - the total C flux (old and new) associated with changes to other land types.
7. 'Net' – the net carbon change

Sample output is mapped and shown in section 5.3.

5.2.3.(b) Monte Carlo estimates

There are uncertainties associated with the land use change data and carbon flux calculations. The mid-point estimates described above do not include these errors. In addition to the LUC matrices used above we can calculate upper and lower bound matrices assuming a given error, say 30%. If we assume these and other parameters (rate of change, equilibrium change in soil carbon density) are uniformly distributed between lower and upper bounds, we can use Monte Carlo methods to select values and repeat the calculation many times to produce uncertainty estimate for the total carbon flux.

The Matlab program required to carry out the Monte-Carlo runs has been prepared but not yet used.

5.3. Results

Results for 1990 and 2003 are presented in Figure 5-3 to Figure 5-8. In each case a comparison is made with the emission or removal calculated for each of the devolved regions as part of the 2003 UK GHG Inventory (2005 submission) described in Chapter 2 of this report.

The results for each region of Great Britain for each land type show good agreement between the national estimate and the sum of the 20 km by 20 km grid cells. There is exact agreement for Northern Ireland as expected because the national rates of land use change data was applied to each grid cell but the agreement is a useful check of the programme coding.

5.3.1. Land Converted to Grassland

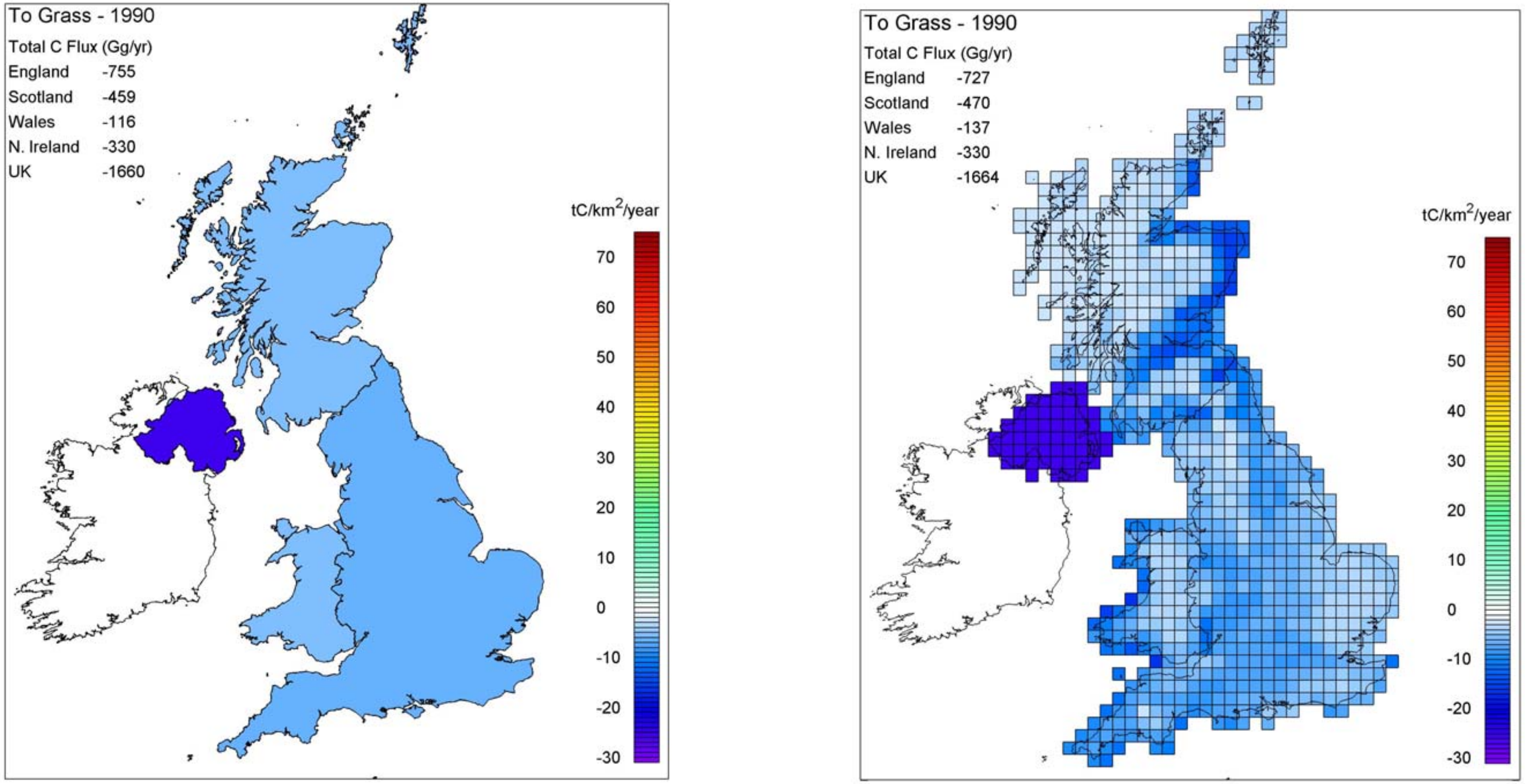
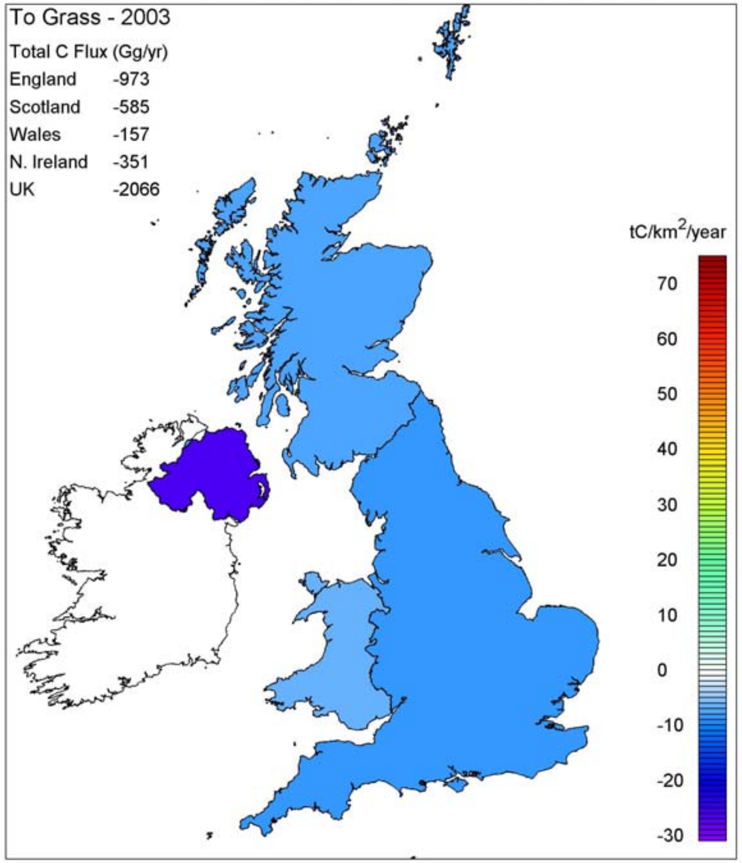


Figure 5-3: Carbon flux associated with land use change to grassland for 1990. National totals compared with 20km by 20km scale data.



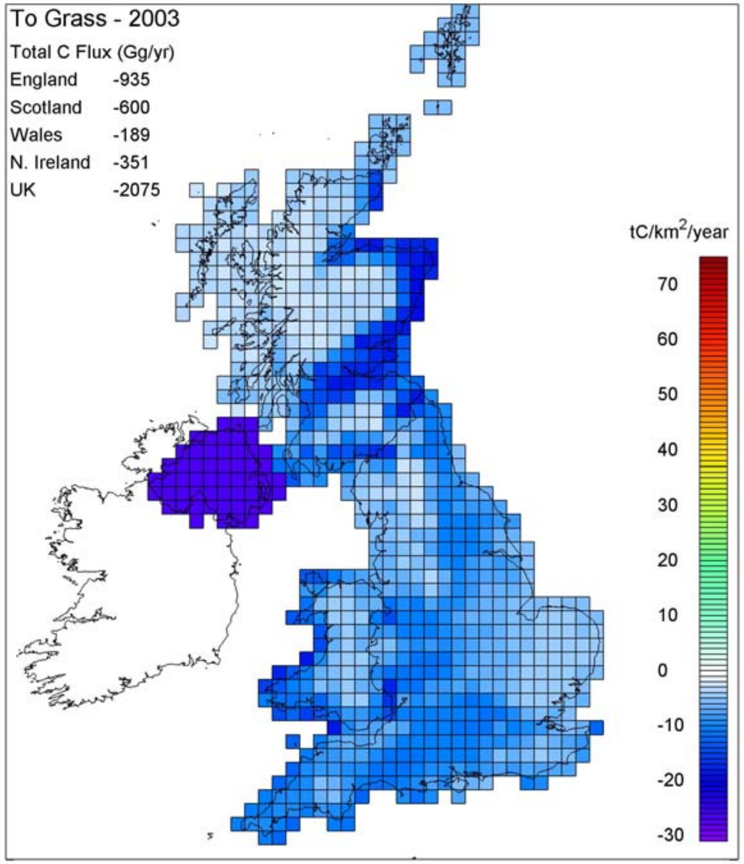


Figure 5-4: Carbon flux associated with land use change to grassland for 2003. National totals compared with 20km by 20km scale data.

5.3.2. Land Converted to Cropland

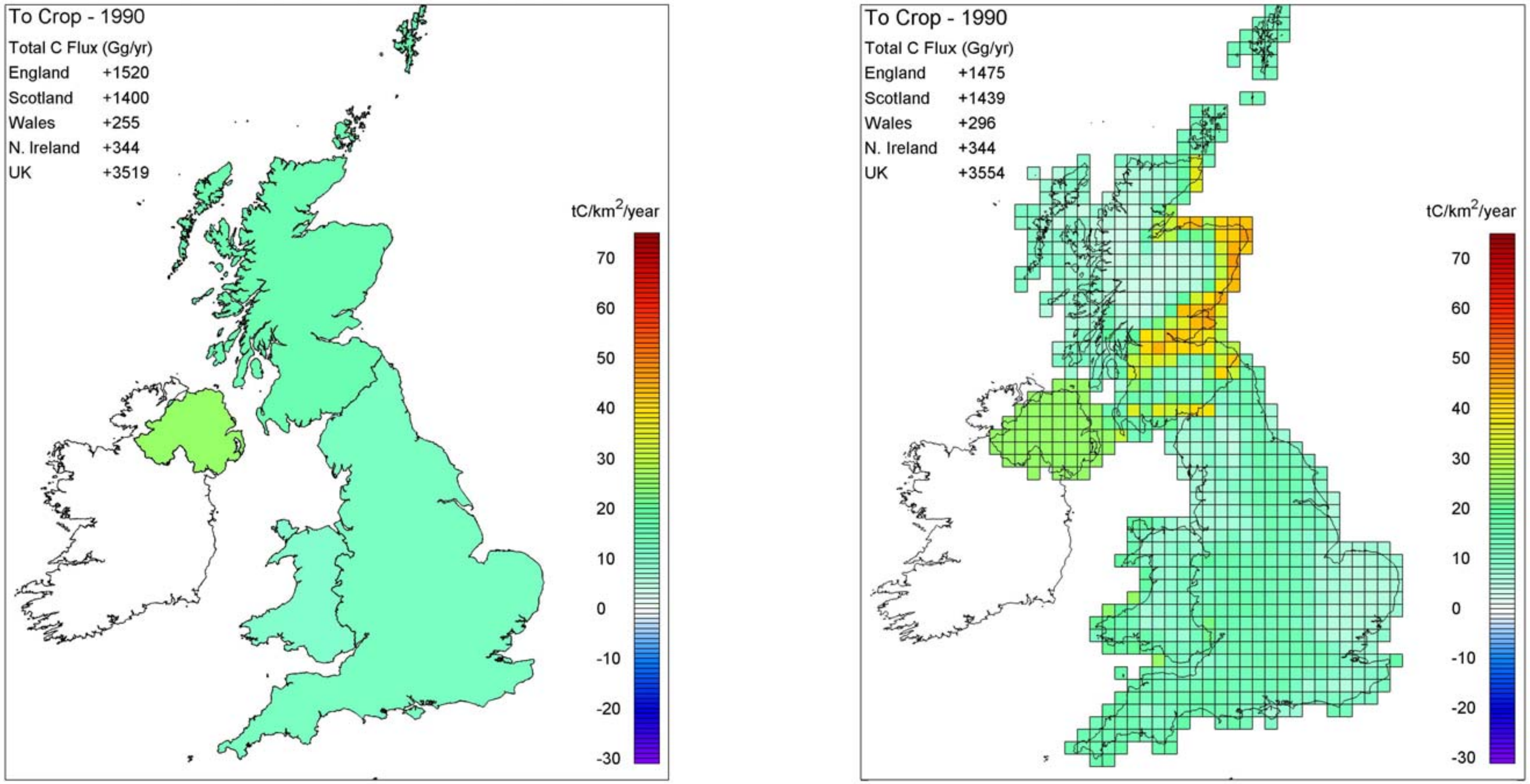
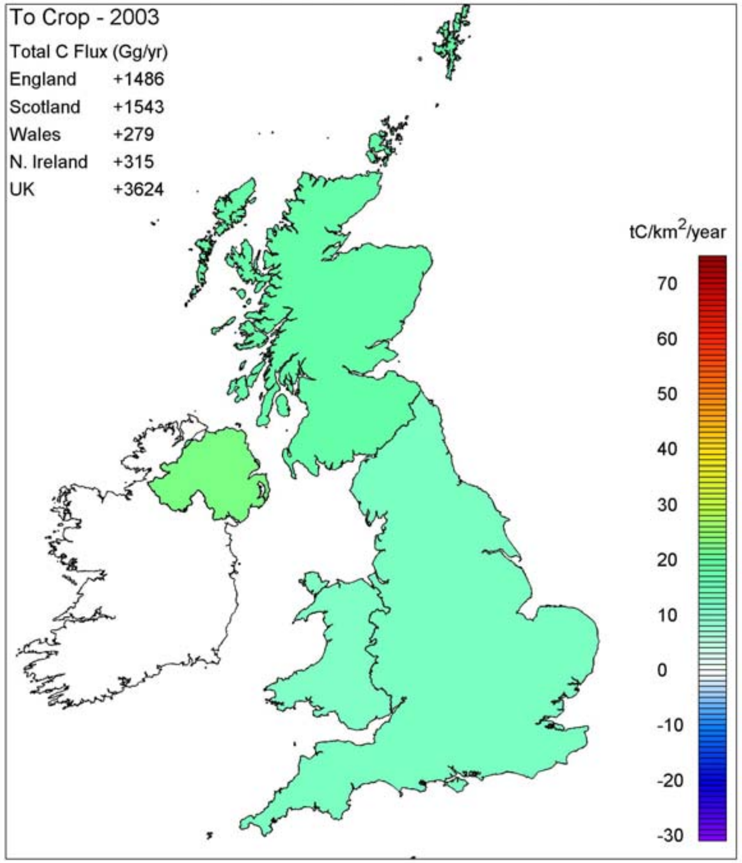


Figure 5-5: Carbon flux associated with land use change to cropland for 1990. National totals compared with 20km by 20km scale data.



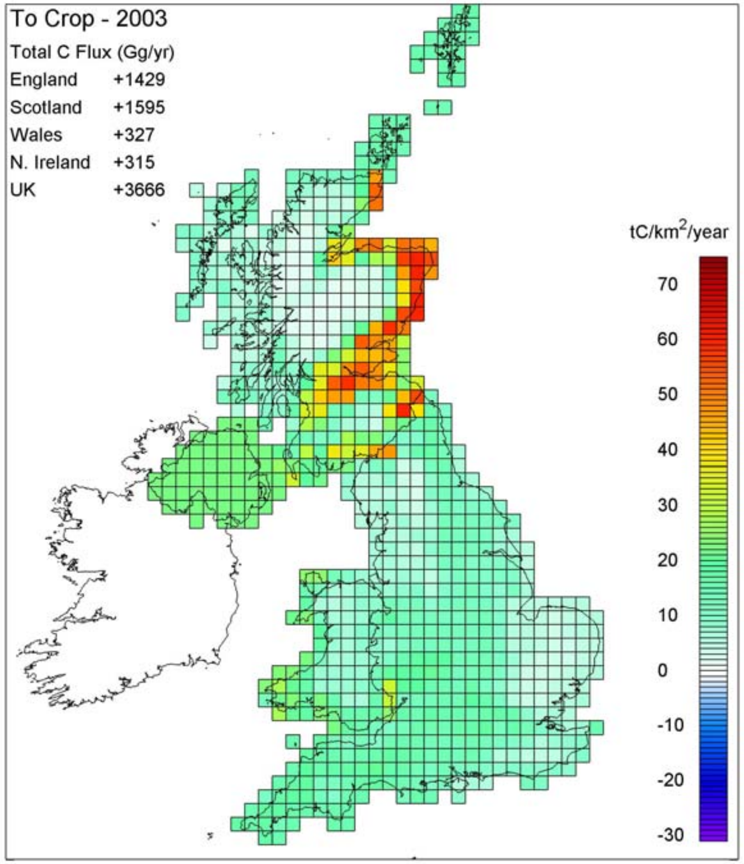


Figure 5-6: Carbon flux associated with land use change to cropland for 2003. National totals compared with 20km by 20km scale data.

5.3.3. Land Converted to Settlement

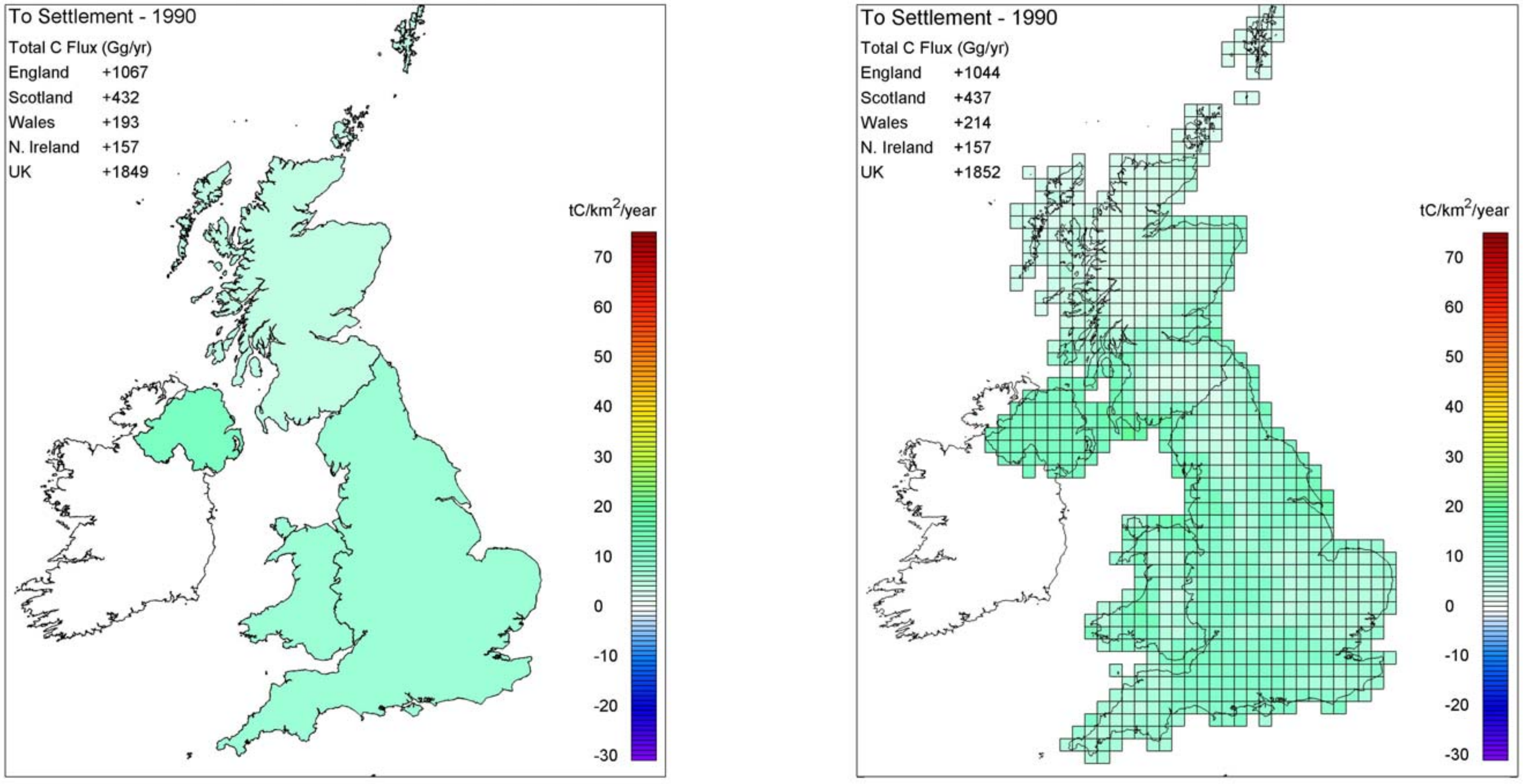
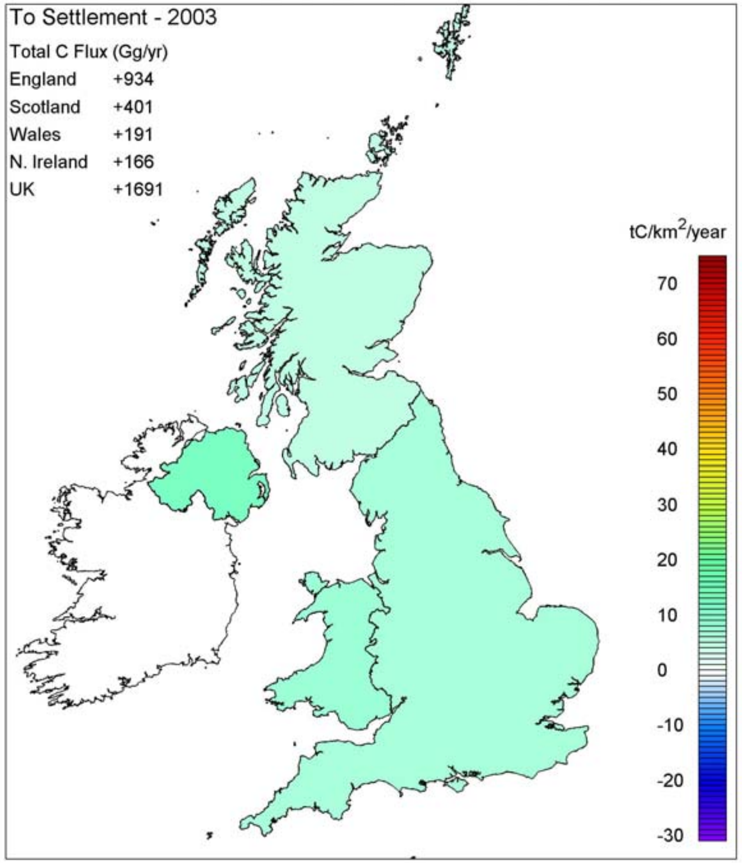


Figure 5-7: Carbon flux associated with land use change to settlements for 1990. National totals compared with 20km by 20km scale data.



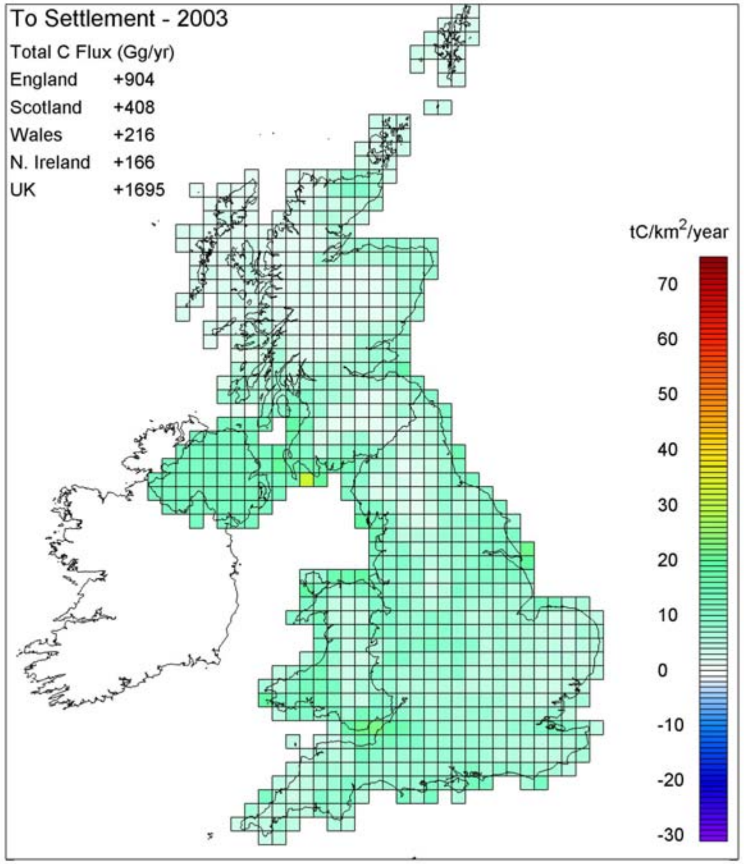


Figure 5-8 : Carbon flux associated with land use change to settlements for 2003. National totals compared with 20km by 20km scale data.

5.4. Future work

Topics for further work are:

- Use land cover maps for 1990 and 1998 as source of land use change for 1990 onward
- Investigate use of county level MLC data for better spatial resolution on land use change in England and Wales before 1980.
- Discussion with AEAT on exact needs for maps suitable for the GHG Emissions Inventory website etc.
- Decide on geographical resolution to be used by UK for reporting emissions and removals by LULUCF under Kyoto Protocol

5.5. References

Milne, R., Brown, T. A. W., (2003). Mapping of carbon uptake in British afforestation and land use change. *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*, (ed Milne, R.). Annual report (2003) for DEFRA Contract EPG1/1/160.

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Section 6

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

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

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3 June 2005.

6.1. Summary

This report details progress that has been made in the development of inventory-based methods for Kyoto Protocol monitoring of forestry based LULUCF activities. A methodology for providing estimates of carbon stocks and stock changes in forest biomass is described together with a detailed description of how verification will be undertaken using data collected as part of the National Inventory of Woodland and Trees. A demonstration of carbon stock and stock change assessment is presented for Alice Holt forest Hampshire, while examples of the verification process are detailed for a range of UK Intensive Forest Monitoring (Level II) plots. The description of the verification process includes an analysis of uncertainty associated with the quantification and use of biomass expansion factors/functions. Tree and stand level (above-ground) biomass expansion factors of 1.35 and 1.31, respectively, are proposed for beech under growing conditions in the UK. The current status of the National Inventory of Woodland and Trees is also presented, with implications for reporting carbon stocks and stock changes in woodland discussed.

6.2. Introduction

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

The purpose of this report is to report on progress made in developing a national forest carbon inventory, including the current status of the National Inventory of Woodland and trees (NIWT: see Smith, 2004) and how this may affect the proposed scheme. Detailed protocols are described for those measures relevant to estimating carbon stocks in NIWT sample squares. A demonstration of the application of BSORT to provide estimates of carbon stocks and stock changes in tree biomass is presented for Alice Holt forest, Hampshire. Finally, an approach to the derivation and verification of carbon stocks is explored for a number of plots comprising the UK Level II network. This approach is based on a nested design in which national-scale surveys are used to provide input data to carbon stock/change models, while smaller numbers of research plots are measured more intensively to provide data for validation of models and verification of estimates (Matthews & Broadmeadow, 2003). Particular emphasis is placed on the application of biomass functions to derive carbon stocks from the yield and inventory models, including an assessment on uncertainty that they may introduce.

6.3. Update on carbon stock assessment protocols associated with the National Inventory of Woodland and Trees (NIWT)

6.3.1. General description of NIWT

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

Once the first cycle is complete the system will provide annual inventory updates in all countries every year. Available resources will dictate the length of the cycle. Many countries have already adopted this system, including USA, Canada, and all the Nordic countries, while France, Italy and some other European countries are currently converting to the system. Twenty four European countries are currently (2004–2008) discussing ways to harmonise inventories, including carbon stock assessments, through COST Action E43 (www.metla.fi/coste43).

6.3.2. Current status

The current National Inventory of Woodland and Trees (NIWT2) is planned for 2006-2015, with an ongoing rolling programme to continue. A pilot exercise was carried out during the summer of 2003, to provide indications of costs and resources required for the full programme of measurements, including options for additional measurements. Discussion of the final details of the protocol and intensity of sampling are still ongoing, and it is unlikely that field measurements will begin until 2006. However, some decisions have been taken, and these are outlined below.

6.3.2.(a) Woodland map

Digital, ortho-rectified aerial photos will be used to update the digital woodland map. Polygon boundaries to will be adjusted to match OS MasterMap where appropriate, potentially giving better fit with other data-sets. The digital photography data-set has been obtained for England and Wales. Coverage is not yet complete for Scotland, but should be by the end of summer 2005. A woodland cover map has been prepared for two pilot areas; a 20 x 20 km tile in southern England, to the south of Alice Holt, and a 100 x 100 km tile in central Scotland. The woodland cover map will include all woods greater than 0.5 ha in area, contrasting with NIWT1 in which the threshold was 2 ha.

6.3.2.(b) Survey cycle

Rather than conduct a periodic survey, a continuous national woodland inventory will be adopted. The cycle is likely to be 10 years to accommodate the expected level of funding.

6.3.2.(c) Sample plot selection

A 1 km by 1 km grid, with 1 ha within each grid square being selected as a sample plot where it lands on woodland. Sample plot numbers will be reduced (for budgetary reasons) by limiting sample squares to those in which at least 50% of the 1 ha patch has woodland cover on the basis of the woodland cover map.

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

A derivation of carbon stocks and stock changes from data collected as part of NIWT2 can only be satisfactorily achieved if mensuration data are collected as part of the core protocol. Soils information are not as essential as mensuration data, although they would provide a valuable verification step and improve the uncertainty estimate associate with soil carbon stocks. At present it seems likely that mensuration data will be collected as part of the core protocol; the situation for soil data is equivocal, and still under discussion. However, whatever the outcome of the consultation process, both mensuration and soil data will be collected in the pilot area to demonstrate the value of both data-sets and how they would be used to derive estimates of carbon stocks and stock changes.

The delay in the start of NIWT2 has implications for the proposed work programme for this contract. Field sampling in the sample squares (as part of NIWT2) will now not take place during the timeframe of this contract. Carbon stock assessments will therefore be made for NIWT sample squares as a separate exercise to NIWT2. Only the core measurements required for carbon stock assessments will be undertaken, as described below. It is therefore proposed that this demonstration phase is restricted to a single pilot area, for which the woodland cover map is already available, and presented as Figure 6-1.

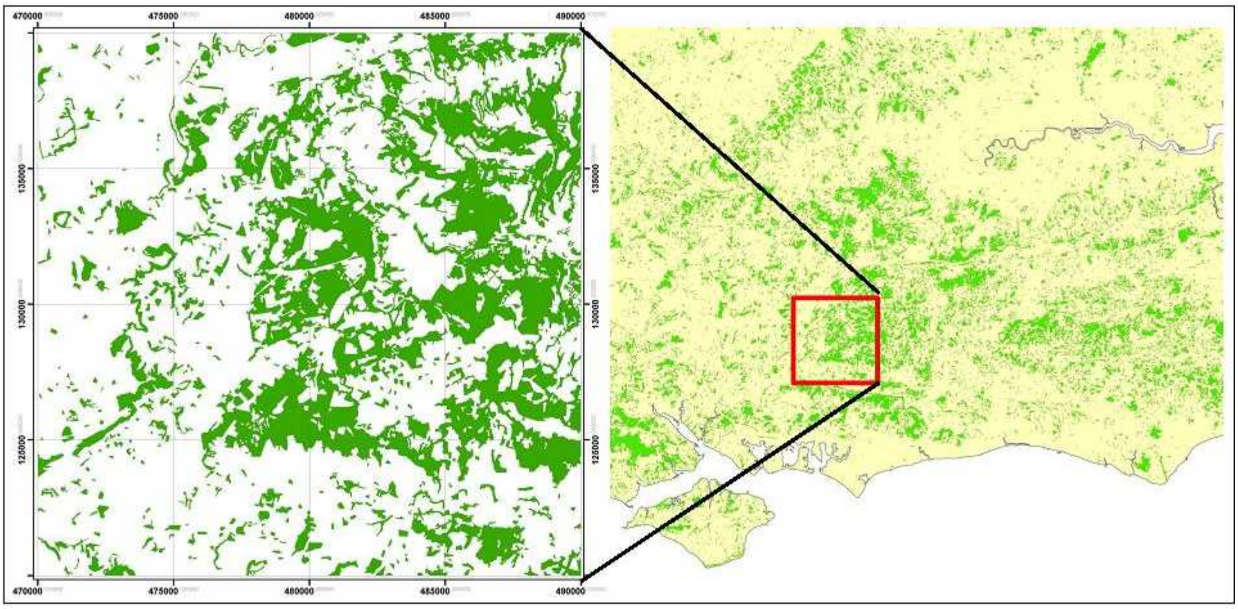

Figure 6-1Woodland cover map (woodland greater than 0.5 ha) for the 20 x 20 km tile in southern England that will be used to test the proposed methodology for the national forest carbon inventory. Maps based on Ordnance Survey Mapping, crown copyright, licence number GD2723882003.

6.3.4. Methodology for deriving carbon stocks in NIWT sample squares

For production woodland, carbon stocks of standing timber will be assessed from conventional yield models underlying BSORT, using the abbreviated mensuration measurements described below as input. Generic models for non-productive woodland are also available. Deadwood assessments and additional measurements made as part of the soil assessment described below will provide an evaluation of carbon stocks associated with litter, but foliage and small diameter branchwood litter will not be accounted for outside modelled estimates from BSORT based on allometric relationships. Soil carbon will be estimated on the basis of broad (detailed FC: Pyatt, 1982; Horne & Whitlock, 1984 – see below) soil type, using modal values for each soil type based on the National Soil Inventory and other available data-sets, including the proposed Biosoil project.

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

6.3.4.(a) General plot attributes

A range of attributes that would be recorded as standard within the NIWT protocol will be recorded. These may have no immediate relevance to the forest carbon inventory, but could be used to inform associated studies, including the availability of woody biomass for bioenergy production (see McKay, 2003).

- Forest type
- Thinning history
- Extractability
- Silvicultural system
- Rotation
- Spacing at establishment
- Recent silvicultural treatment
- Species
- Approximate planting year
- Stocking %
- Health assessment
- Timber potential
- Planted originally
- Timber quality assessment

6.3.4.(b) Soil assessment

Soils will be classified according to the ‘detailed soil-type’ classification given in Horne and Whitlock (1984), enabling verification of information on soil type held in the SCDB. Although the title ‘detailed’ implies a time-consuming assessment, this is not the case, and it is estimated the procedure will take no more than 15–20 minutes. Soil type will be assessed at three locations, basing the classification on soil extracted using a combination of spade and auger; properties necessary for soil classification will be recorded in the field with further chemical analysis in the laboratory not required. Guidance is available in Kennedy (2002). Sampling will take place at the two ends of the linear mensuration transects and their intersection.

In addition to the identification of soil type, the following variables will also be recorded to provide further information for deriving soil carbon content:

- Depth of litter layer
- Depth of ‘O’ horizon (F and H)
- Depth of A horizon

It should also be noted that more detailed soil analysis to 1 m (or bedrock) will be carried out during 2006 as part of the EU (Forest Focus) co-funded Biosoil project. Sampling will take place across the trans-national grid: in the UK, this will be based on the national grid (subject to EC approval), and NIWT sample squares will thus coincide with the ‘Biosoil’ plots. 167 plots have been identified in woodland of greater than 2 ha on the basis of the NIWT1 woodland cover map (see Figure 6-2). The number of plots may rise further (to over 200 plots), once the new woodland cover map is generated, including woodland between 0.5 and 2 ha in area.

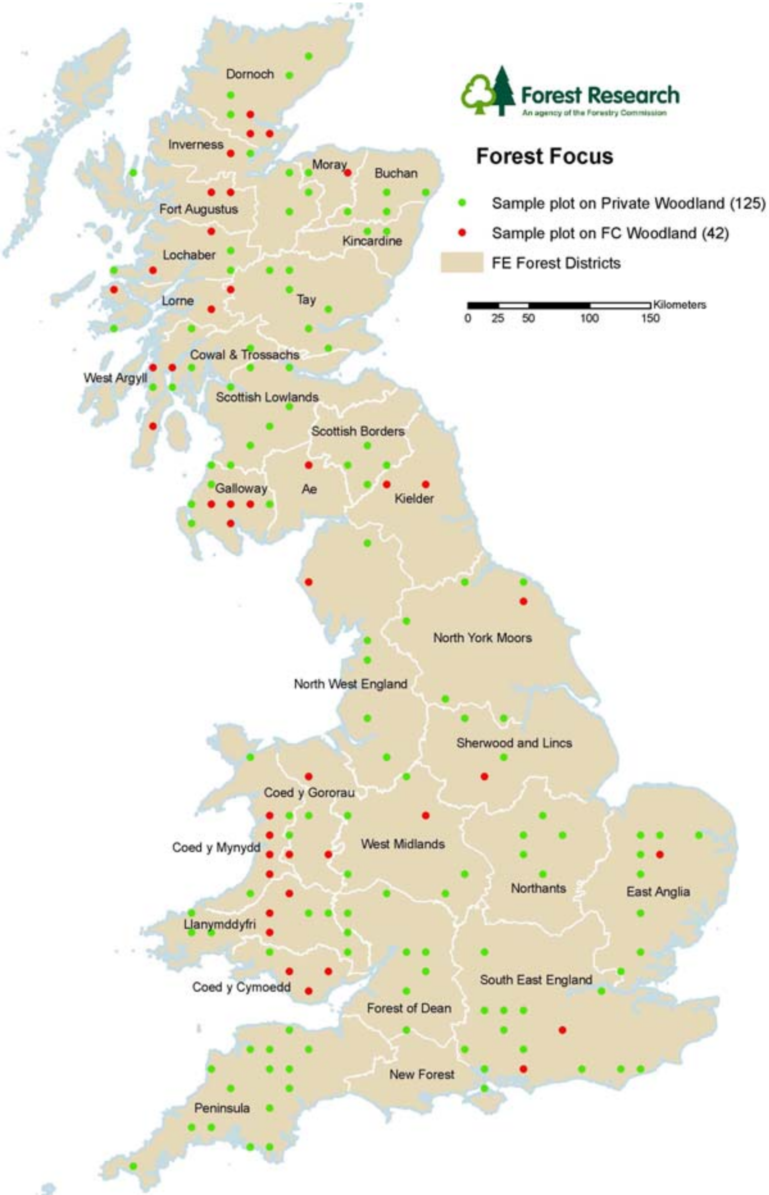

Figure 6-2 Proposed Biosoil network, aligned to the transnational 16 km grid.

6.3.4.(c) Mensuration assessment

The assessment protocol for mensurational variables is still being developed, because of the need to balance essential data requirements for forecasting and carbon stock estimation against available funding. Under the current draft of the protocol, the approach for assessing standing biomass in the central element will not be restricted to a small, defined plot. Instead, linear transects will be employed to provide a more representative assessment of standing biomass. Two transects will be arranged at right angles (an ‘L-strip’), to allow for differences between within and between row spacing to be accounted for in planted woodland.

<u>Definition of L-strip</u>

An L-strip consists of a sequence of 25 living and measurable trees along a straight line, followed by a second sequence of 25 living and measurable trees along a straight line falling at right angles to the first sequence. In practice, the surveyor would make assessments along an initial transect forming the first sequence, starting at an initial tree and proceeding until the 25th tree is reached. This tree would be taken as the 'corner' of the 'L' and would also serve as the first tree in the second sequence. At this point the surveyor would continue along a second transect at right-angles to the first until the final sample tree was reached.

In stands with clearly defined rows of trees, the initial transect should go along a row, with the second transect going across rows. In other stands the direction of the initial transect should be selected at random.

Protocol

- All measurable trees in the L-strip are assessed for dbh.
- Every 4th measurable tree is assessed for total height until there are 10 height sample trees.
- The lengths of the two transects (initial tree to corner, corner to final tree) are also assessed.

6.3.4.(d) Deadwood assessment

A deadwood assessment will be carried out, although it is uncertain whether, at this stage, the assessment will be transect or plot based in the full NIWT protocol. The current preference for carbon stock assessment is for the protocol to be transect based to be compatible with the mensuration assessment. A transect-based assessment will therefore be adopted in the pilot area work programme.

In order to qualify for inclusion, any deadwood must have a minimum mid-diameter of 5 cm and a minimum length of 0.5 m, at least part of which must fall within the plot with the exception of standing trees. The following attributes will be recorded:

Lying deadwood

- Species (or Conifer/Broadleaved/Unknown)
- Mid-diameter
- Length
- Reason for death
- Degree of decomposition

Standing dead trees

- Species (or conifer/broadleaved/unknown)
- Diameter at breast height
- Height
- Reason for death
- Degree of decomposition

Stumps

- Species (or Conifer/Broadleaved/Unknown)
- ‘Top’ diameter, measured overbark
- height to ground level
- degree of decomposition

6.4. Demonstration of application of BSORT to carbon stock change assessment

The majority of models that report woodland carbon stocks and stock changes are based on production, or growth and yield models. This is also the case for BSORT (Matthews & Duckworth, 2005), which additionally incorporates detailed biomass functions (based on a range of published values) for branchwood, stem-tips, foliage and roots. It is thus an improvement on most models which base estimates of non-merchantable biomass on simple biomass expansion factors and root:shoot ratios. The value of diameter, stemwood volume or height-related biomass functions is further demonstrated in below.

The application of BSORT to carbon stock and stock change has assessment has been tested for Alice Holt forest, Hampshire. Alice Holt forest is FC woodland managed for both timber production and amenity. It covers an area of approximately 850 hectares and is planted with both broadleaf and conifer species. There are also significant areas of ancient semi-natural woodland, with some stands over 200 years old. Data are held within the SCDB for individual sub-compartments, with the following attributes relevant to this assessment reported:

- Planting year
- Productivity class (GYC: m^3 ha^{-1} yr^{-1})
- Principal species
- Area planted with principal species
- Total area of sub-compartment

As indicated above, only the area in each sub-compartment planted with the principal species in that sub-compartment is assigned. It was therefore necessary to account for the difference between total sub-compartment area and the area planted with the principal species using the following guidelines:

- If the area planted with the principal species was between 90 and 100% of the sub-compartment area, the balance was assumed to be unplanted.
- If the area planted with the principal species was less than 100%, stock maps were used to identify the identity and planting year of the secondary species; in this case, yield classed was assigned as the average for the species reported for Alice Holt forest.
- If the secondary species was reported as a species mixture, then the balance was assigned to the first named species.

The models available within BSORT do not cover the full range of species and stand ages reported for Alice Holt forest, and the following assumptions were made:

- If stand age was less than the minimum age of the model, then biomass was calculated on the basis of a linear increase in total above ground biomass between planting and the minimum age in the yield model.
- GYC0 was assigned to GYC1
- A nominal planting year of 1953 was assumed for all ‘research plots’ where information was not available; where not stated, mixed broadleaf yield class 4 was assumed.
- Other than for ‘research plots’, where yield class was not given, GYC 2 was assumed.
- Christmas trees plantations were assumed to be GYC 8 Norway spruce planted 5 years before the date of assessment (1995 or 2002).

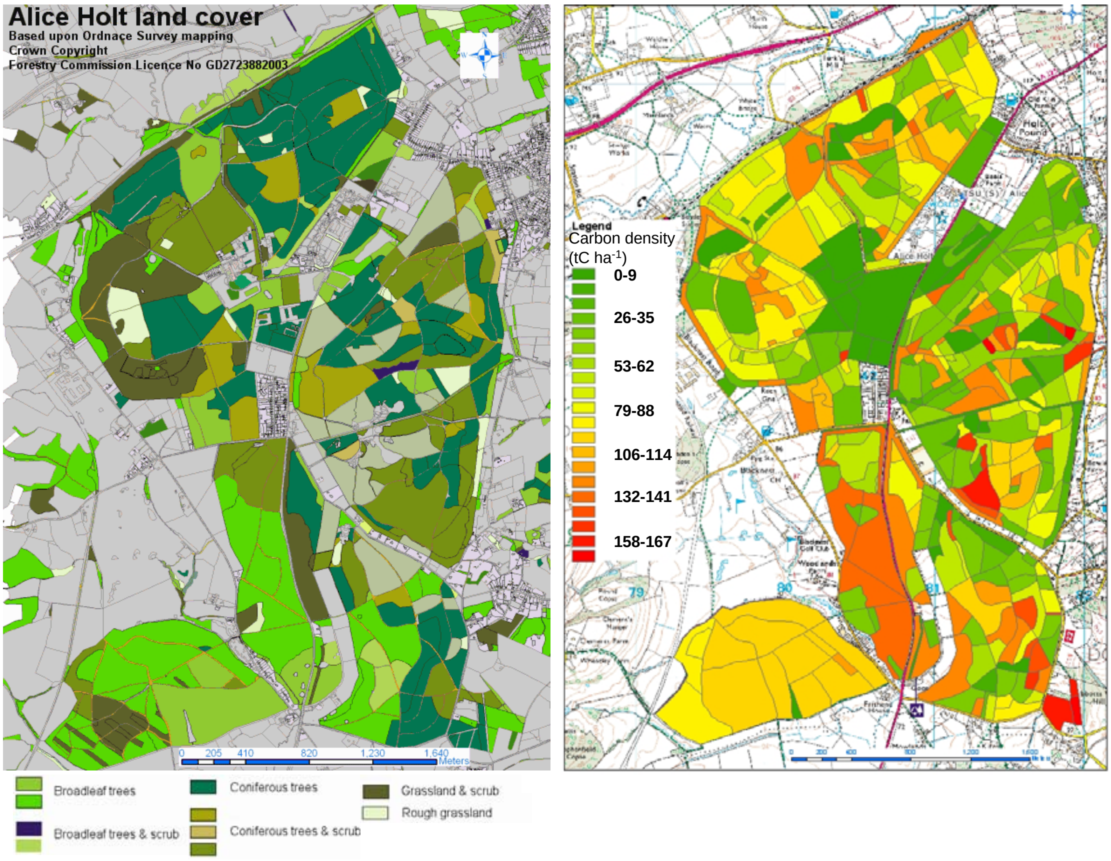

Figure 6-3 (a) Landcover map for Alice Holt forest, (b) map of carbon stocks in woodland biomass for Alice Holt forest, Hampshire. Maps based on Ordnance Survey Mapping, crown copyright, licence number GD2723882003.

Carbon stocks were calculated as total woody biomass (stemwood, branches, branch tips, roots) with an assumed carbon content of 50% (Matthews, 1993). Spatial variation in carbon density are shown in the form of a carbon density map in Figure 6-3. Results shown in Table 6-1 indicate that although the area of woodland fell by 38 ha between 1993 and 2002, there was an increase in total carbon stocks of Alice Holt forest of 11.6 kt C, with the average carbon density of woodland rising by 11.6 tC ha^{-1} from 69 to 81 tC ha^{-1}. This increase equates to an annual increase in carbon stocks in biomass of 1.3 tC ha^{-1} yr^{-1}, agreeing with the estimate of Milne *et al*. (2004), that the carbon stock of woodland in the UK is increasing at a rate of approximately 1 tC ha^{-1} yr^{-1}. The rate of deforestation represented in these data is 0.55%, assuming that no new planting took place between 1993 and 2002. If this rate of deforestation was replicated nationally, it would represent an annual rate of 14800 ha yr^{-1}, at the high end of the range proposed by Levy (2003) but not unreasonable.

Table 6-1 Estimates of changes in standing biomass in stemwood, branchwood, brash and roots in Alice Holt Forest between 1993 and 2002. Average carbon stocks of woodland at each time-point are also given.

	Area (ha)	Standing biomass (tonnes)						Carbon stock (t ha^{-1})
		stem	Branch	Brash	foliage	roots	**total**	
1993	765.5	52148	20789	1648	4165	26898	**105648**	69
2002	727.6	61045	21572	1457	4473	28737	**117284**	81
2002-1993	-37.9	8897	783	-190	308	1839	**11636**	11.6

It is apparent from the assumptions required to carry out the analysis described here that manipulation of the SCDB will be required, before the data held within it can be used for national carbon stock assessments. To accomplish this guidelines, will need to be drawn for default values to complete the driving data-set.

6.5. Derivation of a tree level biomass expansion factor for beech growing in the UK

Eleven of the twenty sites comprising the UK Intensive Forest Monitoring (Level II) network were thinned for silvicultural reasons in 2005. At each of these sites, ten sample trees were selected from across the full diameter range and subjected to detailed mensurational analysis. Results are presented for the six plots planted with beech (*Fagus sylvatica*).

6.5.1. Methodology

The ten sample trees were felled, and conventional mensuration measurements taken: total height; timber height; timber volume to 7 cm diameter. In addition, sawlog volume (>16 cm diameter) was measured. Trees were then separated into five components: stemwood; branchwood (>7 cm diameter); brash; saddle, stump and non-merchantable stemwood; standing deadwood. Each component was weighed separately, using a 50 kg balance (Salter) suspended from a tripod. For each component, three separate samples were taken (where sufficient material was available) and cominuted using an arboricultural chipper. Sub-samples (> 1 kg) were taken off-site in polythene bags for moisture content determination, with additional sub-samples retained for subsequent chemical analysis. Moisture content was determined gravimetrically after drying at 105^{o}C for 48 hours.

6.5.2. Results

Above-ground stemwood biomass was calculated as the product of measured timber volume and specific density (0.55 for beech: Lavers & Moore, 1983). Corrections were not applied for the difference in density between bark (~0.40: ref) and stemwood, to maintain consistency with the approach adopted in the current LULUCF methodology using CFLOW (R. Milne, per, comm.). Total biomass was calculated as the sum of the five components with component specific moisture contents applied to measured fresh weight. Tree level biomass expansion factors were then calculated as the ratio of total measured biomass to estimated stemwood biomass. Figure 6-4 presents the results as a function of measured stem volume, with individual trees across the six sites plotted as individual data points.

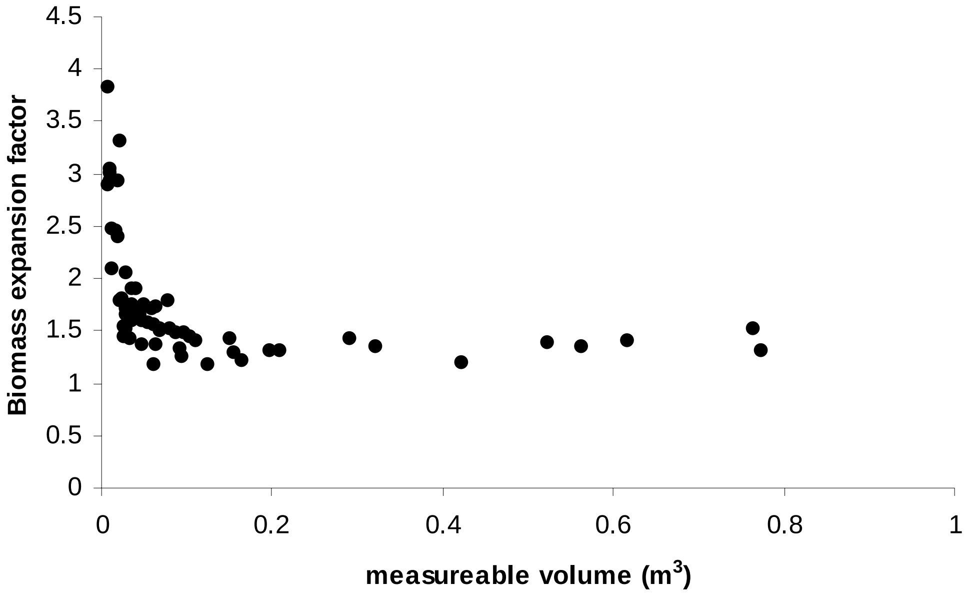

Figure 6-4 Biomass expansion factor plotted as a function of measured stem volume for beech (Fagus sylvatica) in six plots of the UK Level II network.

The data presented in Figure 6-4 clearly demonstrate that the use of a single biomass expansion factor is inappropriate where it is applied to young trees. However, this analysis does indicate that for individual trees of measurable volume greater than 0.1 m^3 (of the order of 15 cm dbh, total height 15 m), the application of a single BEF may be appropriate. A value of 1.35 is calculated as the average BEF for all trees of measurable volume greater than 0.1 m^3. However, it should be noted that the data-set is restricted (16 points), but does include trees from five of the six sites sampled. The value differs markedly from the value of 1.18 that is assumed for broadleaf species in CFLOW (Dewar & Cannell, 1992).

6.5.3. Derivation of plot level biomass expansion function

For each of the six plots, the data described above were used to derive a plot specific relationship between above-ground biomass and basal area. This relationship was then applied to the full diameter distribution reported for the ~0.1 ha mensuration permanent sample plot. A single biomass expansion factor was then calculated for each plot based on all trees present within the sample plot. This value is thus representative of the entire plot and not restricted to the ten sample trees which may not be fully representative of the plot. If plot 1827 is excluded from the analysis on account of the small volume of the individual trees and thus the inappropriateness of the single biomass expansion factor (see above), a mean plot level biomass expansion factor of 1.20 is calculated. It should be noted that the BEFs given in Table 6-2 are based on measured specific density (mean value of 0.59), which is higher than most published values (typically 0.55: Lavers & Moore, 1983). Alternatively, if stemwood biomass is calculated as a product of measured volume and the default specific gravity for beech (0.55), the BEF for the five plots (excluding 1827) rises to 1.31. This is more in line with the value derived from the individual tree analysis described above. This latter value is appropriate if estimates of stemwood biomass are based on measurements of stemwood volume; the lower value of 1.2 is appropriate if measurements of stemwood biomass are available.

Table 6-2 Plot level estimates of stemwood biomass, above-ground biomass and biomass expansion factors for the six beech plots in the UK Level II network. Values of dbh and volume are means of all trees in the sample plot, while estimates of biomass are totals for the sample plot (~0.1 ha).

Plot No.	dbh	Volume	Stemwood biomass	Above-ground biomass	Biomass expansion factor
	cm	m^3	Tonnes	tonnes	
1827: Cannonteign	14.2	15.7	8.7	13.6	(1.53)
1829: Covet Wood	32.5	27.5	15.1	21.4	1.25
1831: Wangford	20.4	34.7	19.1	23.0	1.12
1833: Wykeham	20.5	33.8	18.6	25.3	1.29
2316: Brechfa	21.5	29.3	16.1	21.6	1.24
3766: Kelty	26.0	33.5	18.4	22.3	1.13
Mean					1.20

6.6. Comparison of plot level estimates of above ground biomass – an approach to carbon stock assessment and verification

A number of different options are available for calculating above-ground biomass. These options broadly mirror the range of options that will be applied in a nested scheme to carbon stock and stock change assessment, verification and model parameterisation. At the most basic level, summary patch-level data (age of crop, species and yield class) will be input to inventory or carbon accounting models (BSORT or CFLOW, respectively). This approach will be used to derive carbon stock and stock change assessments from the forest cover map together with associated data from the SCDB or assigned data from the private sector production forecast. The next level of detail involves the input of stand level data in the form of diameter distribution and stocking density. These data will be derived from mensuration data collected as part of NIWT. Upscaled plot-level data using this approach will form the basis of the verification process for national carbon stocks and stock changes. The most detailed level of data input involves the approach described in the preceding section, in which measured biomass in branchwood and other non-merchantable fractions are available. Data input of this intensity is only required to parameterise and/or validate the models that are used for either stock (or stock change) assessment or its verification.

Estimates of carbon stocks in standing biomass are given for the six Level II plots analysed in the preceding section in Table 6-3. It is clear that these estimates encompass a large range of values with, for example, CFLOW predicting only 46% of measured standing biomass, on average. This result is not unexpected, since it is widely acknowledged that the forest management prescriptions assumed in standard yield models do not always reflect actual practice. Local management of stands is known to be a significant influence on standing biomass and consequent carbon stocks (Robertson *et al.*, 2003). Recent developments in computer-based yield models could offer an opportunity to address this issue (www.forestry.gov.uk/forestry/INFD-5XSC7R). A brief description of the approach used to derive each of the estimates of standing biomass is given below:

<u>CFLOW model:</u> Standing volume predicted on the basis of conventional yield models (Edwards & Christie, 1981), with ‘default’ values for specific density (0.55) and BEF (1.18) assumed to derive standing biomass.

<u>BSORT model:</u> Standing volume predicted on the basis of integral yield models. ‘Default’ value for specific density (0.55) applied together with detailed, species group biomass functions to derive standing biomass.

<u>CFLOW plot:</u> Sample plot measurements of standing volume converted to estimates of standing biomass using ‘default’ values for specific density (0.55) and BEF (1.18).

<u>BSORT plot</u>: Standing volume predicted from plot-level diameter distribution, and height-diameter relationship. ‘Default’ value for specific density (0.55) applied together with detailed, species group biomass functions to derive standing biomass.

<u>SPLOT:</u> Plot level standing biomass calculated as described in the preceding section.

Table 6-3 Comparison of estimates of standing biomass (t ha^{-1}) on the six Level II plots planted with beech.

Plot no.	LYC	P-year	Plot measurements			Model estimates	
			SPLOT	BSORT	CFLOW	BSORT	CFLOW
1827: Cannonteign	10	1972	113	133	85	118	47
1829: Covet Wood	8	1950	201	172	168	168	140
1831: Wangford	7	1955	230	237	225	153	104
1833: Wykeham	8	1957	203	169	176	138	112
2316: Brechfa	6	1952	205	236	180	118	95
3766: Kelty	4	1958	222	215	216	78	47
Mean			196	194	175	129	91
% of SPLOT			100	99	89	66	46

6.7. Outlook for 2005-6

Since the NIWT consultation process is unlikely to be finalised before late 2005, the conclusions of the fieldwork undertaken for this project during summer 2005 will be in a position to influence the final methodology adopted for NIWT2. The success, or otherwise, of the protocols described here can therefore optimise relevant protocols, based on practical experience; this will be particularly important for determining whether a soil assessment can be adopted as part of the core NIWT2 protocol, within budget. Based on experience gained in the pilot site assessments, together with the adoption of a final NIWT methodology, a detailed manual for forest carbon stock and stock change assessment will be completed.

Biomass functions will be derived for the remaining 9 Level II plots that were not thinned during 2004–5, enabling the biomass functions used by BSORT to be updated and made fully representative of UK conditions. Other functions relevant to carbon stock assessment will be updated and optimised where appropriate, using data collected in FR forest monitoring programmes.

The development of modelling and assessment methodologies during the past two years will enable carbon stocks in the pilot area to be estimated. Pilot area field assessments will allow upscaled carbon stocks to be calculated, thus demonstrating whether the proposed approach to a nested assessment – verification procedure is achievable.

6.8. Acknowledgements

The authors thank Christine Brown and Peter Crow for providing graphics and Andy Moffat for helpful discussions. The hard work of John Proudfoot, Ian Craig, Rory Cobb and, particularly, Steve Coventry, James Duff and Harry Watson in assessing stand level biomass is greatly appreciated. The Forestry Commission (Corporate and Forestry Support) is acknowledged for part-funding the work.

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Section 7

Estimating Biogenic Carbon Fluxes from Flux tower measurements and Earth Observation data

Version date 16th June 2005

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7. Estimating Biogenic Carbon Fluxes from Flux tower measurements and Earth Observation data

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7.1. Rationale

The research effort within CTCD has three main objectives, all of which relate to DEFRA's interest:

1. Provision of 'best possible' process-based biospheric carbon flux estimates at local, catchment, UK, European and continental/global scale, together with well-founded estimates of uncertainty, partitioned into uncertainty arising from internal parameters, input data, initial conditions and model deficiencies.
2. Development of methods to reduce the uncertainty in carbon flux predictions by combining data with models, with special emphasis on the use of EO data.
3. Investigation of new sensors, theory and information recovery methods that have the potential to improve our estimates of carbon fluxes.

A key feature of the CTCD is its highly integrated approach, shown schematically in Figure 7-1, involving dynamic models that are based on the latest process understanding, strongly linked to EO data and ground measurements, and coupled with state of the art treatment of uncertainty. This comprehensive structure allows us to make particular contributions to terrestrial carbon cycle science by characterising uncertainty in model calculations and using EO data to reduce this uncertainty.

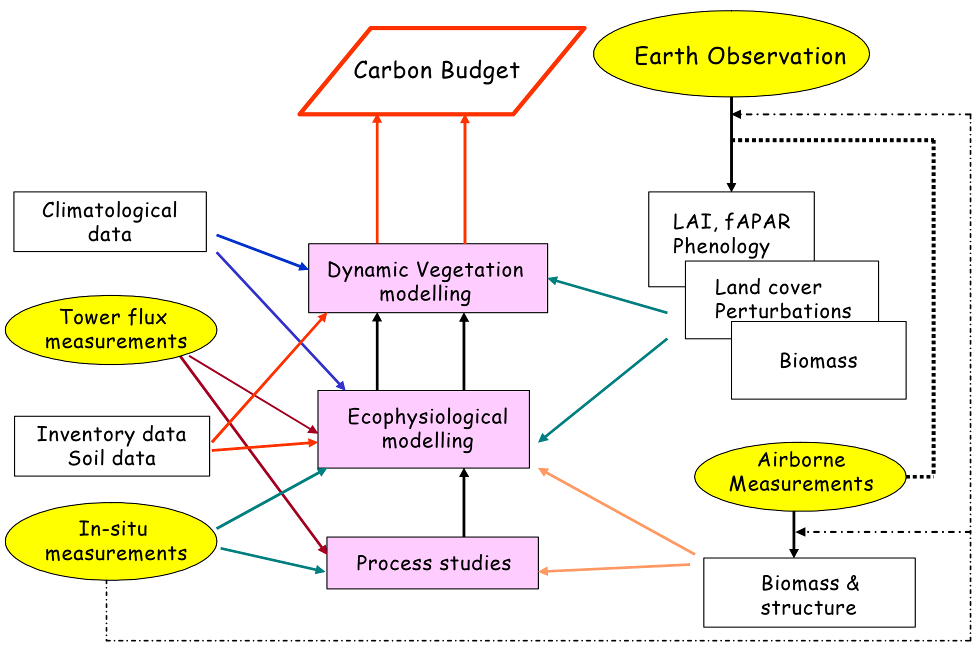


Figure 7-1: The inter-linking of models and measurements within the CTCD. Threaded through the whole structure is characterisation of uncertainty and its consequences.

Here, we report especially on the aspects of the research that relate to the UK biospheric carbon fluxes, and we give preliminary estimates of the UK fluxes based on three different methods.

7.2. Models and model testing

Three models to calculate carbon fluxes are in use within CTCD: SDGVM (Sheffield), SPA/DALEC (Edinburgh) and ForestGrowth (Forest Research). Tests of the models against CO_2 flux data were presented last year in our Annual Report.

SDGVM has been the main workhorse around which uncertainty methodology has been developed and tested; it has provided simulations in steps towards data assimilation and for comparison with EO models for global primary production; it has also been used to calculate uncertainty associated with simulating vegetation phenology; and it has been used in investigations of uncertainty raising from soil carbon parameters and the temperature responses of soil respiration.

SPA/DALEC is the central model for data assimilation, providing a method for spatial extrapolation and process investigation of CO_2 flux observations from flux towers.

ForestETP and **ForestGrowth** are detailed and site-specific Forest Research models used in quantifying how process generalisations in SDGVM and other models affect the reliability of the calculations. Their calculations provide critical comparisons with CO_2 flux calculations by SDGVM and SPA, and they are also the appropriate models for studying the effects of forest management on carbon dynamics. ForestGrowth provides simulations of detailed site-specific CO_2 exchanges of trees and forests suitable for driving and developing process-based soil models. In addition, ForestGrowth 3-D, with its description of dynamic canopy architecture as a function of radiance, competition and growth can and will be run to simulate radiance for comparison with EO data.

A key development has been to demonstrate that readily-available information on run-off can reduce the uncertainty in carbon flux calculations. First of all, simulated monthly and annual stream flows for the catchments were compared with long time-series observations for 29 large catchments in the United Kingdom. Figure 7-2 compares simulated stream flow by SDGVM with observations for four of these catchments ranging in annual precipitation. In 23 out of the 29 catchments, the bias between model and observations was found to be less than 10% of precipitation. In the remaining catchments, larger errors are due to unpredictable causes, in particular various human activities and measurement issues; in two cases, the causes were unidentified. Hence overall the hydrology module in SDGVM was confirmed to work reliably in the UK.

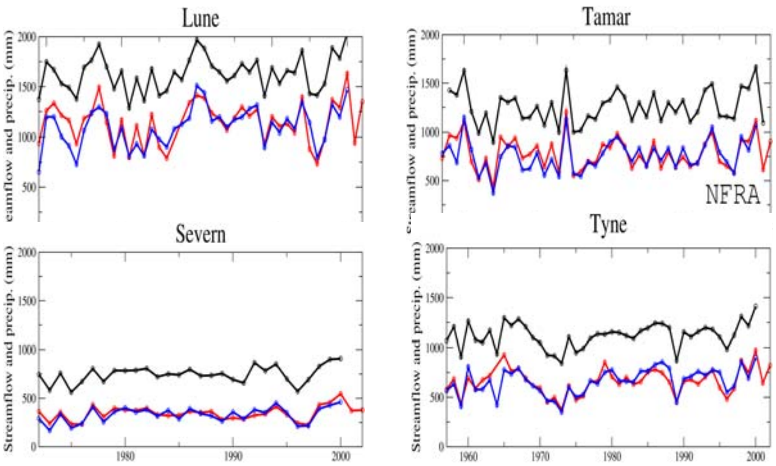


Figure 7-2: Plots of observed annual stream-flow (red line) and annual stream flow simulated by the SDGVM (blue line) using CRU climate data or NFRA climate data (NFRA is printed on the plot). Annual precipitation (black line) is also shown

While SDGVM is a generalised model designed for regional scale simulation, ForestGrowth is designed to simulate the dynamic growth of trees in semi-natural and managed landscapes, particularly at individual and stand scale, and uses species rather than the plant functional types of SDGVM. The soil-vegetation-atmosphere transfer (SVAT) model (ForestETP) at the core of ForestGrowth predicts transpiration, evaporation, the vertical and lateral water movement through the soil-plant-atmosphere continuum and gross primary productivity. This SVAT model has been extended to account for the effects of topography and the heterogeneity of surface properties on the water and carbon budget, and the impact of land cover and land change on catchment discharge. This makes it possible to simulate and partition the sub-daily and aggregated dynamics of water flow.

The ForestGrowth model is currently being integrated with the Century soil C-N biogeochemical model to allow a full assessment of C stocks and fluxes accounting for catchment hydrology, including the impacts of both climate change and N deposition on growth dynamics, and their effects on water quality and quantity at the catchment scale.

A key point of these detailed and site-specific Forest Research models is that they allow us to quantify how process generalisations in SDGVM (and other models) affect the reliability of the calculations. They are also the appropriate models for studying the effects of forest management on carbon dynamics.

One of the greatest difficulties, in modelling the carbon fluxes over forests, is the problem of accounting for age-related effects resulting from forest management. Information on the age structure of plantation forest can be inferred from ERS Tandem coherence, particularly the younger stands. The relation between age and coherence varies with weather conditions, and the SPA model was coupled with a simple scattering model to explain the temporal behaviour of coherence; the variation was reasonably well explained but not the magnitudes. This analysis showed that the high variability of the water content of the canopy makes a model-based inversion of coherence to age very unreliable, and forces a fall-back onto empirical methods. These were applied to 1995 data for the UK, where we have very good forest age information from Forest Research with which to calibrate the inversion. NEP varies strongly with age for younger stands, then becomes stable; this behaviour is matched to the age sensitivity of coherence. Coherence was used to produce estimates of the age structure and NEP from all UK forests (Forest Commission and private). The results indicate significantly different age structures between Wales and the rest of the UK, and significantly larger values of NEP than are produced by inventory methods. Jointly with Gamma Remote Sensing, we have assessed and compared the ability of L-band radar (JERS) and coherence to detect clear-cut. Accuracy levels are around 90% for both techniques. Three papers on measuring forest age and clear-cut using have been submitted.

7.3. Influence of land cover parameterisation

Our models currently impose an externally provided land cover, typically derived from EO observations, to constrain the proportion of Plant Functional Types (PFTs) within a given area. The unavoidable errors in such land cover maps introduce uncertainty into model calculations. The aims of this work-package are (i) to develop methods for assessing the uncertainty in model-predicted C budgets due to uncertainties in the land cover data; (ii) to assess the associated uncertainty, initially for the UK, then Europe, then globally.

Generic methods have been developed for this type of assessment and have been used to provide uncertainties in carbon fluxes (GPP, NPP and NEP) over the UK. The concept is very simple. For fixed land cover, the PFTs do not compete. Hence the SDGVM can be run over the region of interest populated with a single PFT. The calculation for a given land-cover then just involves linear summation of the estimated flux for each PFT, weighted by the proportions of each PFT in a grid-cell. This approach allows quick calculation of the effects of uncertainty in land cover on

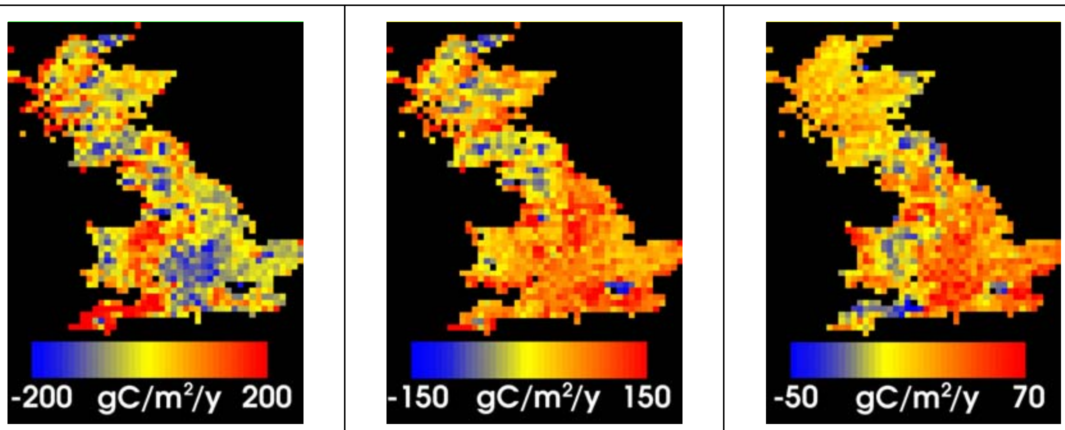
C fluxes. For the UK, the uncertainty in GPP is estimated using a high spatial resolution land cover map (LCM2000), an independent assessment of the error in LCM2000 (a ‘confusion matrix’), and a coarser spatial resolution global land cover map (GLC2000).

Figure 7-3 shows the differences in flux estimates between the GLC2000 and the LCM2000 for the UK. Positive values (red) indicate an overestimate by the GLC2000. The mean difference in GPP for the whole of the UK is close to zero, but there is a strong positive bias in the estimates of NPP and NEP derived from the GLC2000. Table 7-1 shows the mean UK fluxes derived from the two different data sets.

Many of the discrepancies between the two data sets can be explained by the effects of heterogeneity. The base resolution for the GLC2000 is 1 km whereas the LCM 2000 is a 25 m product and thus capable of describing much greater levels of complexity in the landscape. Flux in urban areas, for example, is always lower using GLC2000 than when using LCM2000, because far fewer urban green spaces are represented at the 1 km scale.

The main generic result is that the impact of uncertainty in land cover depends on how strongly the fluxes of the individual PFTs differ. For example, the GPP of crops and C3 grasses are normally very different (C3 grasses tend to have a higher GPP). Thus large uncertainties in land cover maps between these two PFTs will have a strong impact on overall uncertainty. This is especially important because the spectral signatures of these cover types are similar and are thus likely to exhibit a high degree of confusion in EO-derived land cover maps.

A journal paper for submission to Remote Sensing of Environment is nearly completed.



(a) ΔGPP (b) ΔNPP (c) ΔNEP

Figure 7-3: Differences in carbon fluxes calculated using the LCM2000 and the GLC2000. Areas in red are where the GLC map overestimates the flux and blue where it underestimates it in comparison to the LCM2000. Yellow denotes areas are where there is only a small difference.

Table 7-1: Mean carbon flux for UK in the year 2000 derived using the LCM2000 and GLC2000 land cover data sets.

	GPP (gC/m^2)	NPP(gC/m^2)	NEP(gC/m^2)
GLC2000	1302.73	850.93	138.37
LCM2000	1290.17	800.08	119.16

7.4. Data assimilation

Our critical achievement this year has been the publication of the first paper to demonstrate how C flux and stock data can be assimilated into a terrestrial C model. We used the Ensemble Kalman filter with a simple C box model, and pool and flux observations, to generate improved estimates of C dynamics for a pine stand in Oregon, USA (Williams *et al.*, 2005) . We also showed how the assimilation of photosynthesis observations, which can be derived from EO data, generates a measurable and important reduction in error bars on the estimates of net ecosystem exchange (Figure 7-4).

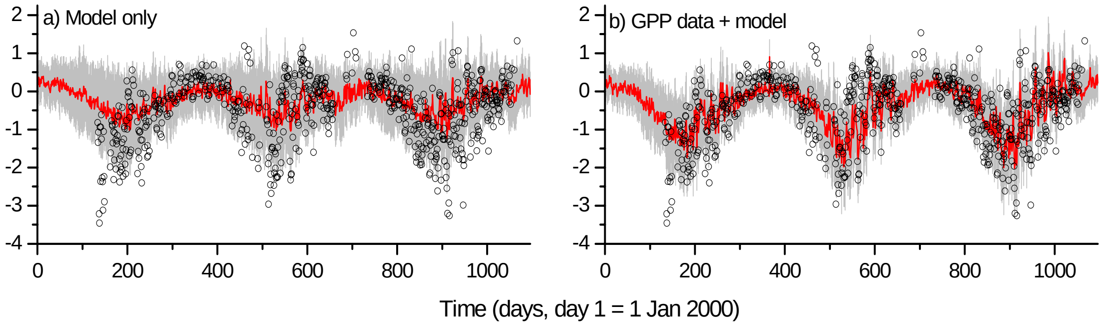


Figure 7-4: The panels show daily analyses (red lines) over three years of net ecosystem carbon exchange (NEE) for a young ponderosa pine stand in central Oregon. These were generated using (a) model only, no observations; b) model plus GPP (derived from sap flow data) estimates only. NEE observations from an eddy flux station are shown as open circles. Grey lines indicate the standard deviation around the mean of the ensembles used in the data assimilation.

We know from experimental data that the pine stand is drought stressed during late summer. The box model used in the DA scheme did not relate photosynthesis to soil moisture, which forced shedding of leaf area in the summer to reduce photosynthesis, in line with the alteration in the flux data. We were able to identify this inconsistency because leaf area data contradicted this change. Consistency checking of this type is a key strength of DA. To overcome this drought problem, we have constructed a new version of the DALEC model with coupled carbon and water fluxes (Figure 7-5). The coupled model has been tested over three years at the pine site, and produces realistic simulations of the development of drought stress (Schwarz *et al.*, 2004). However, the lack of a snow model in DALEC causes some inconsistencies, and we are now investigating a simple snow model. Once complete, DALEC will be a globally applicable, simple, coupled C-water model that can be used in the twin experiment. The advantage of DALEC is that the majority of its state variables are simply related to observations, meaning that it is optimally constructed for use in assimilation schemes.

To predict photosynthesis (GPP) and evapotranspiration (ET), the DALEC model uses components called emulators, which are constructed from the detailed SPA model. Using a tested aggregation scheme (Williams *et al.*, 1997) we have generated simple flux emulators of daily GPP or ET, dependent on daily drivers. These emulators are useful because they have reduced driver requirements and are 3-4 orders of magnitude faster than SPA. The emulators allow us to include realistic representations of the multi-dimensional response surfaces of GPP and ET.

Other progress has been an exploratory coupling of the SPA model with a model of the planetary boundary layer. This will allow us to test the consistency of flux data at the land surface with measurements of CO_2 concentration from tall towers or aircraft, and is a first step in being able to assimilate concentration data. In preparation for the regional assimilation experiment in central Oregon, we have begun to assemble and generate the relevant spatial data sets. This is an area with a rich array of flux towers, stand-level surveys and EO data, spanning a major precipitation gradient, and with significant fire disturbance, so an ideal test arena for our DA scheme. Finally, we are using frequency domain analysis of the DALEC model to determine the necessary sampling rate for effective data assimilation (i.e. how often and over what period should observations be available?).

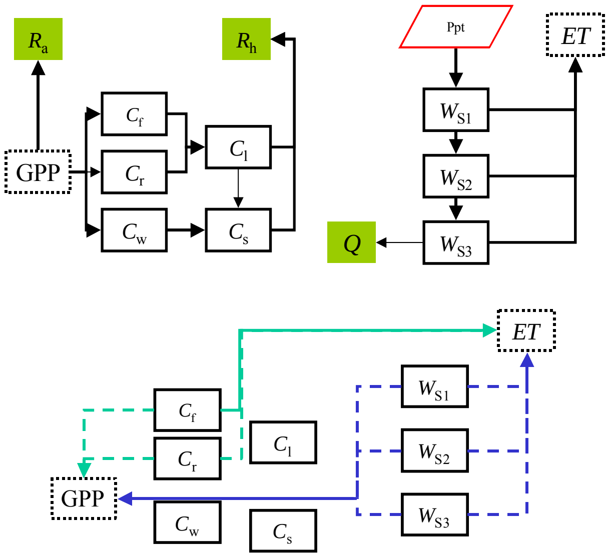


Figure 7-5: The Data Assimilation Linked Ecosystem Carbon (DALEC) model, version 2. The original DALEC model simulated C dynamics alone. We have now added a simulation of soil moisture dynamics, and coupled the carbon and water fluxes. The left half of the figure shows the state variables, both stocks (solid boxes; C = carbon, r: root, f: foliage, w: wood, l: litter, s: soil, Ws: soil water content in numbered soil layers), emulated fluxes (dashed boxes; GP: photosynthesis, ET: evapotranspiration), input fluxes (red rhombus; Ppt: precipitation), and fluxes exchanged across system boundaries (green boxes; R: respiration, a: autotrophic, h: heterotrophic, Q: discharge). The right half shows the influences (dashed lines) that connect state variables with the emulators of GPP and ET, generating feedbacks.

7.5. Incorporating new data

7.5.1. Flux data

CarboEurope-IP is continuing to collect and archive new data from forest, grassland and farmland, as itemised in our 2004 Report, which are now coming available to modellers.

We deployed the short 'roving' tower for making new measurements at a heather *Calluna /Sphagnum* bog within Harwood Forest in Northern England. This heather-dominated vegetation covers much of northern Britain, and constitutes the native vegetation on which plantations have been established. The data show fluxes that are usually one-third to one-half of those observed for Sitka spruce, and the ecosystem appears to be a very weak C sink. Figure 7-6 shows the light response curves of uptake of CO_2 for midsummer: in bright sunlight (over 1000 µmol photons m^{-2} s^{-1}) spruce accumulates carbon at a rate of about 15 µmol CO_2 m^{-2} s^{-1} whilst heather accumulates only at 5 µmol CO_2 m^{-2} s^{-1}. The data so far suggest that the bog is only a very weak carbon sink.

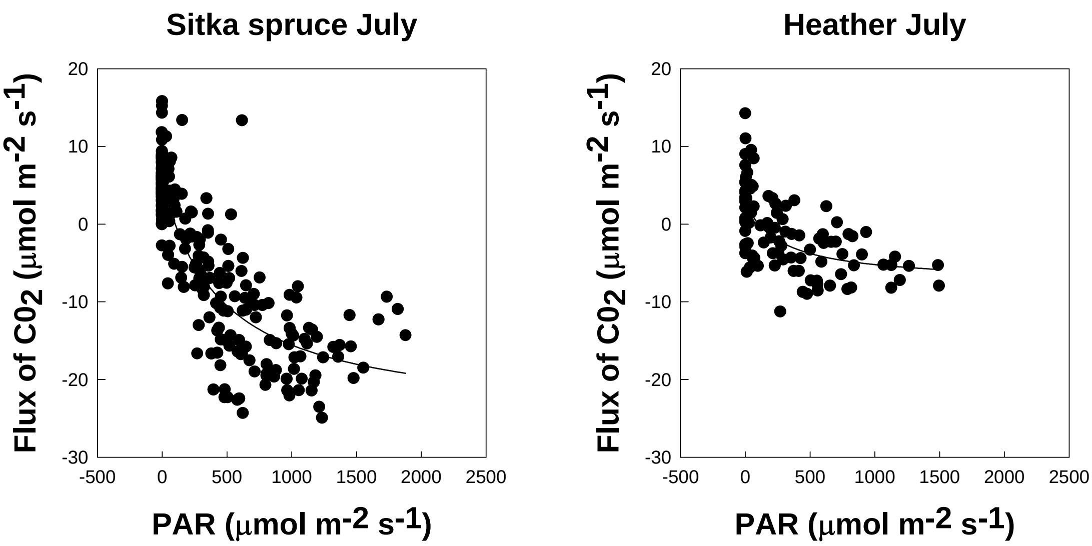


Figure 7-6: Eddy covariance flux data of spruce and heather compared at the Harwood site. Fluxes are plotted (y-axis) against the incoming photosynthetically active radiation (x-axis). The data points are half-hour averages and the fitted line is a rectangular hyperbola. Uptake from the atmosphere is shown as negative, by convention. Ecosystem respiration (from the fitted hyperbola) was 5.5 ± 0.5 μmol CO_2 m^{-2} s^{-1} and 2.7 ± 0.7 μmol CO_2 m^{-2} s^{-1} respectively for spruce and heather.

7.5.2. Reducing uncertainty in carbon stocks of soil

Information on soil is a core requirement of the CTCD, affecting all model calculations of C fluxes. Soil texture databases are basic inputs to the models; soil C maps allow model testing; measurement and differentiation of C fluxes from soils provide insights into processes and form part of our intensive site-based measurement programme; these insights will hopefully lead to improved representations of processes for incorporation in the models; and more fundamental models based on soil biology provide the future of understanding what drives C fluxes in soils. Figure 7-7 compares the most recent CTCD UK 'best estimate' of soil C stocks at two grid scales, based on field data, vs. SDGVM model outputs (far right). Any discrepancies in modelled soil C stocks amplify through to major uncertainties in predicting terrestrial C fluxes; a principal generic failing in all DGVMs is their inability to accurately model organic soils. The central theme of soil research within CTCD is to identify and reduce these uncertainties.

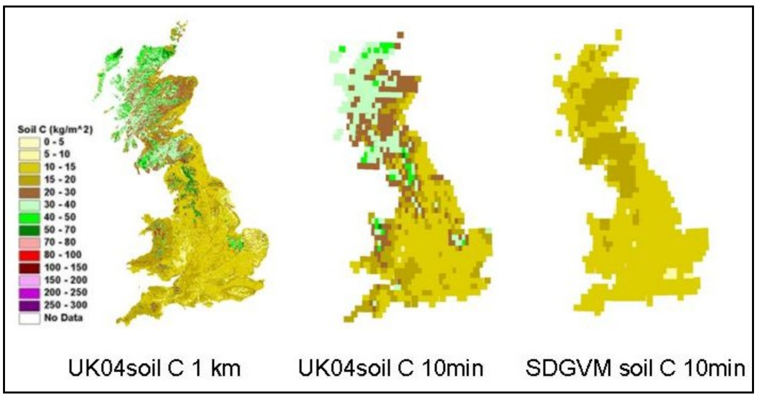


Figure 7-7: Observed and calculated soil stocks

An important, substantial and unanticipated task arose when the basic soil C stock dataset, obtained from DEFRA, via Silsoe and MLURI, was found to contain many important errors and regional inconsistencies. Working with the data providers, the dataset was carefully examined to identify and rectify errors (e.g. incorrect bulk density values, misclassified grid squares, etc). We now have an acceptable UK dataset, where any further improvement would not deliver any significant improvement in comparison to the additional effort required. These data were provided to the CTCD data manager in mid 2004 and a full list of necessary corrections has been returned to the data providers to enable them to modify the original dataset.

A similar effort was required to identify and correct errors in the UK soil texture data. However, this is limited to texture data from England, Wales and Northern Ireland. Data from Scotland are excluded because of major unresolved problems with access to these data and this compromises all models and maps which we produce for the UK.

In collaboration with the statisticians at Sheffield, the LCM2000 land cover database and UKCIP/BADC data are being used with the latest soil C database to investigate relationships between contemporary UK climate and current soil C stocks. This involves Bayesian methods to deal with censored data (i.e. maximum C densities within a fixed soil depth). We find that contemporary mean annual air temperatures are the best predictor, being inversely correlated with soil C stocks. These results are currently being compared with soil C estimates generated from SDGVM and European data.

7.6. Overall biogenic carbon fluxes and uncertainty calculations

SDGVM was used to make uncertainty calculations of the Net Ecosystem Productivity for England and Wales. The calculations took into account uncertainties in (a) soil texture and bulk density (b) uncertainties in the parameters defining Plant Functional Types, but currently we have ignored uncertainties in climate data, land cover and model structure. The uncertainty limits for parameters including ‘budburst limit’ and ‘evergreen leaf lifespan’ were defined by elicitation of the experts’ knowledge by the modellers.

Figure 7-8 maps the results of the uncertainty analysis of NEP, accounting for uncertainty in PFT parameters, soil texture and bulk density. It does not yet account for uncertainty in land cover (work reported in Strand 3 suggests that this may not affect total NEP much, but there will be local effects on both best estimates and their uncertainty), in monthly climate data (and its disaggregation to daily data by the SDGVMd weather generator), or in model structure.

On the left of Figure 7-8 is a map of the correction that should be applied to the SDGVMd NEP output that is obtained by running it with the ‘best estimates’ of all parameters. The correction arises as a combination of uncertainty in those estimates and the nonlinearity of the model. The right hand side of Figure 7-8 maps the standard deviation of the NEP estimates due to uncertainty in soil and PFT parameters.

Two papers describing this work are in draft form.

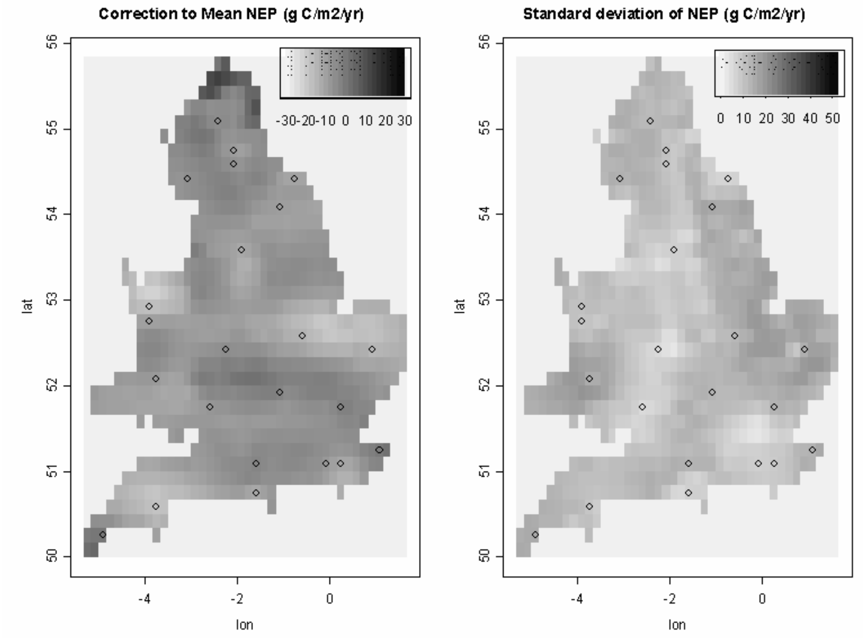


Figure 7-8: Uncertainty analysis correction to SDGVM (see text).

For England and Wales the uncertainties in carbon fluxes are shown in Table 7-2. The aggregate estimate for the carbon flux is 3.63 +/- 0.49 MtC per year, of which the forest component is 0.56 MtC. This is smaller than the corresponding inventory values. Cannell & Dewar (1995) used forest inventory to calculate a carbon sink of 2.5 MtC for the UK; of this, we may estimate a figure of 1.1 MtC for England and Wales. Inventory data produced last year by CEH were essentially the same as Cannell & Dewar's published result based on a somewhat more advanced approach (8444 Gg of CO_2 is 2.30 Mt C). A third independent estimate, albeit a rough one at present, can be obtained from eddy covariance measurements: productive plantation forests may be expected to have a NEP of 4-6 tC ha^{-1} yr^{-1} when in their middle age, but only 2-3 when considered over their entire life cycle. Allowing for some forests to be less productive, we think an average for UK forests is likely to be a sink of 2 tC ha^{-1} yr^{-1}. Multiplying this by the land area of England and Wales suggests a forest sink that is higher than any of the above values, of 2.6 MtC.

Table 7-2 Estimated carbon flux obtained from running SDGVM. The uncertainties ascribed to the estimates are based on a preliminary uncertainty analysis. In the case of the 'crops' component, consumption of the production is not accounted for.

	Estimate (MtC)	**Range (+/- as a percent)**
Crops	2.24	20
Grasses	0.83	6
Deciduous	0.41	8
Evergreen	0.15	8
Total	3.63	14

7.7. Priorities for next year

(i) A top priority is to reconcile the differences in estimates of the carbon sink from different methods, and to extend the CTCD estimate to include Scotland.

(ii) To utilise new data sets coming available from CarboEuropeIP

(iii) to make new estimates of the biogenic fluxes using atmospheric measurements (from tall towers and aircraft)

7.8. Glossary

BADC	British Atmospheric Data Centre
CRU	Climatic Research Unit
DALEC	Data assimilation linked ecosystem carbon
EO	Earth Observation
ERS	Series of satellite missions (1991, 1995) by the European Space Agency
ET	Evapotranspiration
GLC2000	Global Land Cover 2000 is a remote sensing product from the European Space Agency
JERS	Series of satellites from the Japanese Space Agency (Japanese Earth Resources Satellite) from 1992
LCM2000	Land Cover Map 2000 is a high resolution land cover map of the UK
NBP	Net Biome Productivity, an expression of carbon flux which includes disturbance and is relevant for regional scale budgets
NEE	Net Ecosystem Exchange is a high resolution measure of carbon flux, using the sign convention whereby gains by the atmosphere are positive
NEP	Net Ecosystem Exchange is a high resolution measure of carbon flux, using the sign convention whereby gains by the atmosphere are negative
NPP	Net Primary Productivity is photosynthesis minus plant respiration
PAR	Photosynthetically Active Radiation, is the radiation between 400 and 700 nm, usually expressed as μmol photons m^{-2} s^{-1}. A mol of photons is Avagadros number of photons.
PFT	Plant Functional Type (eg deciduous tree, C4 grass)
SDGVM	Sheffield Dynamic Global Vegetation Model
SVAT	Soil Vegetation Atmosphere Transfer Scheme
UKCIP	UK Climate Impacts Programme, established 1997.

7.9. References

Cannell, M. G. R., Dewar, R. C. (1995). The Carbon Sink Provided by Plantation Forests and Their Products in Britain. *Forestry*, **68,** 35-48.

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Williams, M., Rastetter, E. B., Fernandes, D. N., *et al.* (1997). Predicting gross primary productivity in terrestrial ecosystems. *Ecological Applications*, **7,** 882-894.

Williams, M., Schwarz, P. A., Law, B. E., *et al.* (2005). An improved analysis of forest carbon dynamics using data assimilation. *Global Change Biol*, **11,** 89-105.

Section 8

Use of the Rothamsted Carbon model, RothC, in deriving the UK Carbon inventory

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8. Use of Rothamsted Carbon model, RothC, in deriving the UK Carbon inventory

AP Whitmore, K Coleman, Rothamsted Research

8.1. Background

RothC has been developed to run a the 1km scale and so, potentially, provide detailed information on the change in C stocks under different land-use changes throughout the UK. Direct implementation of RothC into the inventory would be possible but would need substantial modification of the current system. A better course of action might be to test the equivalence of RothC with the current 'coefficient method' in order to see if RothC could inform the choice of coefficients rather than form the hub of the inventory. This would enable us to take a long-term view about how when or if to incorporate RothC into the inventory fully and allow us to evaluate the potential benefits of such an incorporation completely. In this respect we note that the New Zealand inventory employs similar technology and that while the Australian inventory makes use of RothC it has done so by re-writing the code and incorporating this into their reporting system

Figure 8-1 may help to make this clear

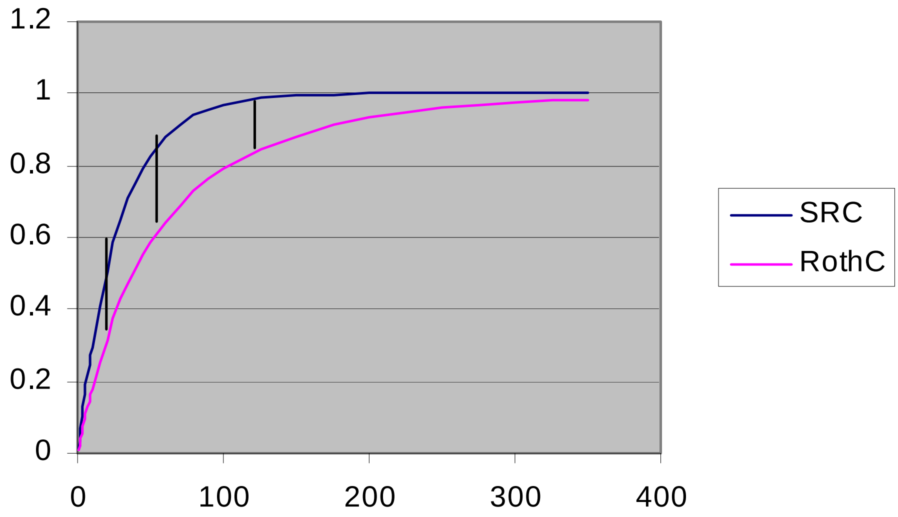

Figure 8-1 Mapping RothC onto a single exponential model in stages

A simple, single exponential model of the decomposition or addition of decomposing crop residues tends to predict a too rapid change in the amount of carbon stored in soil as a result of land-use change. RothC separates soil C into 5 different pools the decomposition of which is controlled by exponential decay. Some pools decompose in parallel with others, most in sequence. The result is a more realistic and versatile description of organic matter dynamics in soil. The price to pay, however, is complexity and our thesis is to see if there is a middle way that is less complex but sufficiently realistic. In Figure 8-1 we have mapped the accumulation of C in soil as a result of land-use change onto that predicted with RothC. Intuitively, then it would seem possible to use RothC to say what the coefficient for a transition described by a single exponential should be at any one time and for how many years that coefficient should be used. The reality is more complex and this report deals with our initial investigations. We hope to report more fully at the end of the next reporting period

8.2. Methods

In order to investigate the possibility of mapping RothC onto the coefficients currently in use in the inventory we looked at a number of situations:

Four land-use changes investigated:

- Pasture to arable
- Pasture to semi-natural
- Pasture to Forest
- Arable to Forest

Several Functions investigated:

- Double exponential (parallel model)

$$C = A_2(1-\exp(-k_1 t)) + A_2(1-\exp(-k_2 t)) \qquad \text{eq 8-1}$$

- Sequential single exponentials

$$\begin{aligned} C &= A_1(1-\exp(-k_1 t)); t < t_1 \\ &= A_1(1-\exp(-k_1 t_1)) + A_2(1-\exp(-k_2 t)); t. >= t_1 \end{aligned} \qquad \text{eq 8-2}$$

- Fully flexible exponential fits

$$C = A_2(1-w_1\exp(-k_1 t)) + A_2(1-w_2\exp(-k_2 t)) \qquad \text{eq 8-3}$$

where C is the change in soil carbon, A_1 and A_2 are coefficients representing the change in C stock and k_1 and k_2 are coefficients representing the rate of that change and t_1 is the time at which a transition from one set of coefficients to another takes place.

The four land-uses represent important transitions in land-use. Others will be straightforward to include. As stated above RothC works with a number of pools of C in soil, the decomposition of each being controlled by an exponential decay function. Middle ground with the current methodology in the inventory suggests some sort of multiple exponential but these could be in parallel eq 8-1 or in sequence (eq 8-2, and as in Figure 8-1). Equation eq 8-3 is a more empirical but complete mathematical description that was found to map output from RothC very well. It is difficult, however, to ascribe physical significance to the weighting coefficients w_1 and w_2 in mapping onto the decomposition processes in RothC.

Because the fits with eq 8-2 were less good than expected a fourth model was then evaluated:

$$\begin{aligned} C &= A_1(1-\exp(-k_1 t)); t < t_1 \\ &= A_1(1-\exp(-k_1 t_1)) + A_2(1-\exp(-k_2 t)); t. >= t_1; t < t_2 \\ &= A_1(1-\exp(-k_1 t_1)) + A_2(1-\exp(-k_2 t_2) + A_3(1-\exp(-k_3 t)) \end{aligned} \quad \text{eq 8-4}$$

Which model was best was decided by using a variance ratio (F) test as follows, where ΔRSS is the change in the residual sum of Squares in moving from one model to the next, ΔDF is the change in the number of degrees of freedom and RMS is the residual mean square

$$F = (\Delta RSS / \Delta DF) / (\text{RMS most complex model})$$

This $F_{(\Delta DF,\ DF\ \text{most complex model})}$ was tested against statistical tables

8.3. Results

In general the three equations eq 8-1 to eq 8-3 could be mapped onto output from RothC well. The more coefficients the better the fit, however. In particular the use of eq 8-2 led to a fitting problem at the transition, as shown in Figure 8-2

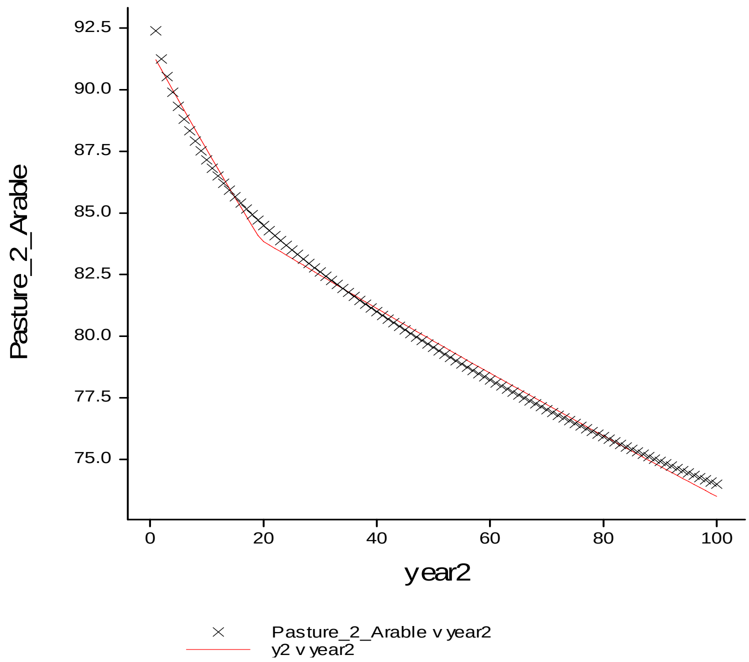

Figure 8-2 Mapping two sequential exponentials onto output from RothC

Moving to three sections appears to solve this problem and fits for all four land-use changes are shown in Figure 8-3

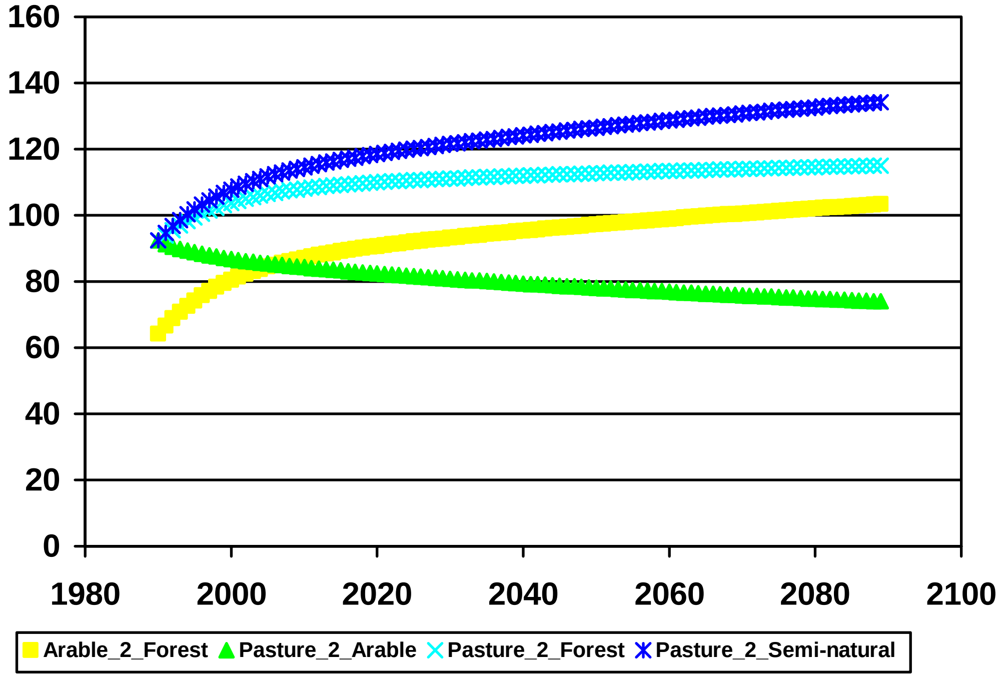

Figure 8-3 Change in C stock with time

Although there a large number of parameters to be determined in order to use eq 8-4 many of these are common among land-use changes and different models. For example the equilibrium values for each land-use will be the same on the same soil type and under the same climate. The start and end values then become common (Figure 8-4).

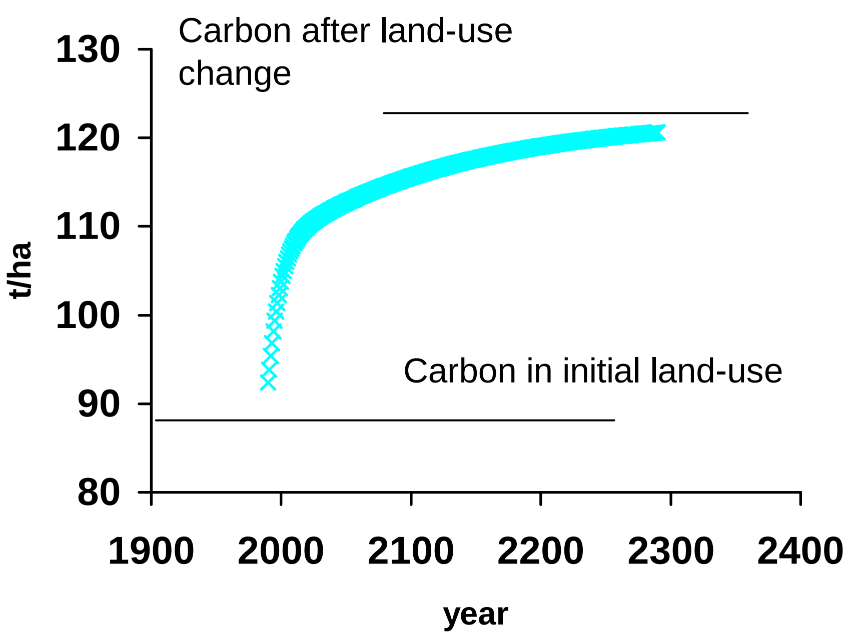

Figure 8-4 Change in soil C relative to equilibrium values

It appears likely that the transition times (t_1 and t_2) are similar for all land-use transitions investigated so far but that they differ depending upon whether carbon is increasing with land-use change or decreasing (Figure 8-5)

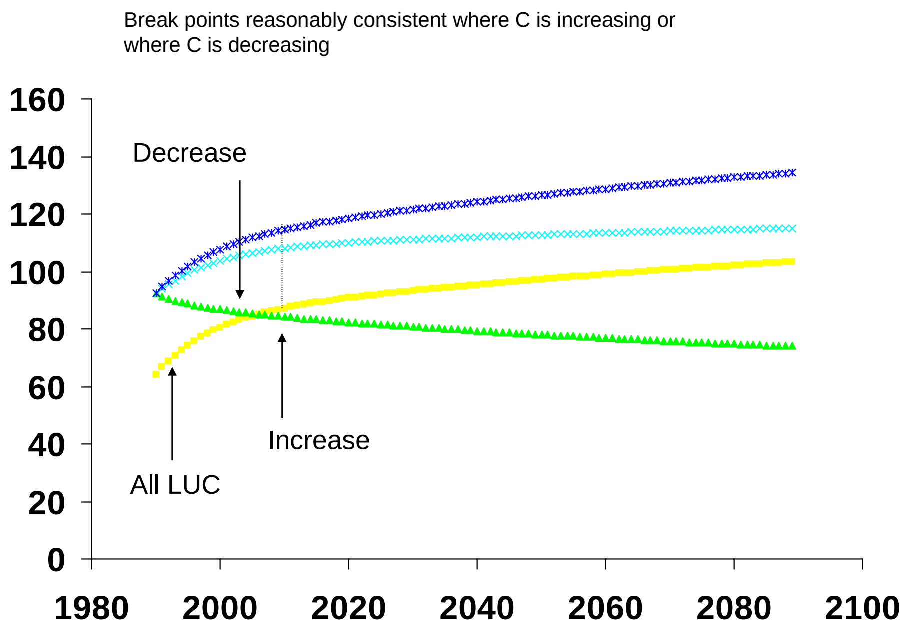

Figure 8-5 Location of break points during change in soil C as a result of land-use change

8.4. Discussion

All of Eqs eq 8-1 to eq 8-4 map to RothC reasonably well. eq 8-1 has the advantage of simplicity and fits better than eq 8-2. eq 8-3 fits very well but is difficult to tie into reality. Eeq 8-4 fits better than eq 8-3 with parameters that have physical meaning but is more complex than either eq 8-1 or eq 8-2.

A further advantage of eq 8-4 over eq 8-1 is that the parameters appear to be consistent over different land-use changes. Subsequent work will focus on confirming that this is indeed so. An important issue here is that of accuracy. The effect on the inventory of small errors such as that introduced by eq 8-2 needs to be investigated but it must be remembered that the deviation shown in Figure 8-1 is of a simpler model from RothC. eq 8-2 may be perfectly adequate in the face of real information we have on land-use change. However, there is still the issue of stability of parameters to consider and here we expect eq 8-4 to be best model.

Section 9

RothC-BIOTA v05 plant-soil C turnover model – parameterization and evaluation

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9. RothC-BIOTA v05 plant-soil C turnover model – Parameterization and evaluation.

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9.1. Introduction

The Rothamsted Soil Carbon model has been developed so that it can use the UK soils database to simulate changes in soil carbon, for possible future use in national GHG inventories (Falloon, 2004). The model uses either fitted soil carbon inputs, or crude estimates of carbon returns per month for a range of plant functional types. The limitation of this approach is that the model does not dynamically respond to changes in climate and land-use. In order to simulate such changes, alternative methods of calculating C returns are required, such as those from dynamic plant growth models that respond to atmospheric CO_2 increase, and changes in climate as RothC does for the soil components. One such model is Biota (Wang *et al.*, 1995). BIOTA, a process-based model describing photosynthesis at the canopy level and C transfers in the plant/soil system, has been linked with RothC v26.3 (Coleman *et al.*, 1996), a functional model of C turnover in topsoils. Initial development of the link was presented by Milne *et al.* (2004). In this chapter, we report recent developments of the coupled model, namely improvements in the range of plant functional types (PFTs) and crops included, the efficiency and functionality of the code and the accuracy of the simulations. We report in detail on further improvements of the design, parameterization and initial evaluation of the coupled model.

9.2. Calculating carbon returns to the soil for various crops

The first step in model development for new PFTs and crops is to estimate the proportion of the total dry matter each month that is returned to the soil. This varies greatly among PFTs as well as among different crop types. In order to develop carbon return proportions, so that carbon inputs to the soil each month could be calculated from total plant carbon, relationships between plant carbon and soil inputs from the SUNDIAL agro-ecosystem model (Bradbury *et al.*, 1993, Smith *et al.*, 1996) were adapted and parameterised. This was summarised in an Excel workbook (for transparency of calculation), referred to as the DEBRIS calculator.

In previous work, the BIOTA model was provided with parameters to enable simulation of plant growth for selected arable crops (Milne *et al.*, 2004). These have now been refined and extended to further develop the default parameters quantifying monthly litter production for different crops. The DEBRIS calculator has been used to estimate:

1. proportions of standing plant biomass that are returned to soil as plant debris at monthly intervals during the growing season,
2. proportions of plant biomass removed from the field and incorporated into the soil as crop debris at harvest.

The DEBRIS calculator estimates C additions to soil from different plant components at different growth stages (equation 1). These relationships were developed over a number of years at Rothamsted Research by J.U. Smith, M. Glendening and G. Tuck, on the basis of field measurements provided by A. MacDonald and P. Poulton, and other published field experiments.

The DEBRIS calculator applied a SUNDIAL function (eq 9-1) to estimate monthly C inputs to soil from plant debris. Those estimates were then related to the cumulative C in the growing plant, to estimate fractions of C in plant biomass that are returned to soil each month. Fractions for each crop are used as BIOTA input parameters in the crop.ini files.

$$C_{inDebris} = C_{inCrop} \times ((C_{ao} - C_{st})/C_{ao}) \times \exp(-kc \times w) \qquad \text{eq 9-1}$$

where: $((C_{ao} - C_{st})/C_{ao})$ and *kc* are SUNDIAL fixed parameters for each crop and *w* is the number of weeks till harvest [converted to month for use in BIOTA].

At harvest, we applied the SUNDIAL method to estimate the fraction of C in crop biomass removed from field as yield (eq 9-2), and the fraction in cartable crop residues (straw and other crop debris) (eq 9-3). The latter can be added to soil or removed at harvest, which will vary depending on site management.

BIOTA has so far been parameterized for seven crops (Table 9-1), but the DEBRIS calculator will be further applied to define parameters for all crop types including root crops.

$$C_{off} = 0.4(85\%G) \qquad \text{eq 9-2}$$

$$C_{cartable} = c5(1 - c6 \times e^{c7G}) \qquad \text{eq 9-3}$$

where : G – yield, c5-c7 – SUNDIAL parameters.

Table 9-1 Input DEBRIS parameters(proportion of the total cumulative C in the total biomass present in that month) for all seven crops types.

crops	**Spring wheat**	**Spring barley**	**Winter wheat**	**Winter barley**	**Spring oilseed rape**	**Winter oilseed rape**	**Field peas**
Max. debris input at harvest (1)	0.314	0.194	0.274	0.195	0.366	0.338	0.288
Pre-harvest input (1)							
Jan	0	0	0.598	0.082	0	0.090	0
Feb	0	0	0.496	0.100	0	0.116	0
Mar	0	0	0.318	0.094	0	0.120	0
Apr	0.074	0.428	0.174	0.080	0	0.140	0.138
May	0.066	0.306	0.108	0.120	0.140	0.134	0.162
Jun	0.068	0.322	0.054	0.132	0.122	0.162	0.136
Jul	0.130	0.444	0.044	0.192	0.154	0.332	0.170
Aug	0.146	0.390	0.044	0	0.306	0	0
Sep	0	0	0	0	0	0	0
Oct	0	0	0	0.015	0	0.014	0
Nov	0	0	0.548	0.019	0	0.020	0
Dec	0	0	0.446	0.034	0	0.036	0

9.3. Resolving problems with the coupled model when performing an equilibrium run

RothC-BIOTA v97 was applied to simulate SOC under seven selected cereals (Table 9-1). The results for total SOC, estimated with the soil module (excluding the BIOTA component), using debris inputs based on previous RothC applications, were very low. They ranged from 6.9 tC/ha for soils under field peas to 14.5 tC/ha for soils under winter barley. When the BIOTA component was used, soil C sequestration was increased to 23.5 – 33.1 tC/ha for field peas and winter wheat respectively. The soil carbon stock simulated with the stand-alone version of RothC was very low in comparison with previous RothC results which suggested a total SOC of 33.8 tC/ha simulated for spring barley (Coleman *et al.*, 1996). In this respect, the coupled model apparently performed better. Very low predicted SOC values for RothC in the coupled framework suggested problems with the model structure, which were investigated further. We also observed a very large increase in SOC pools simulated for cereals with the coupled models in the first 10 years. RPM, however, reached equilibrium more slowly (after 100 years in comparison with 30-40 in previous studies). The sudden change of slope in the HUM pool for cereals after 100 years suggested a problem in the coupled model framework (Figure 9-1A).

When annual change in SOC was estimated for each individual year (Figure 9-1B), a rapid drop in SOC was seen after 10, and then 100 years. Those results contrasted with RothC simulation for spring barley and suggested that there might be an artefact associated with the three step process used to assess the equilibrium soil carbon stock.

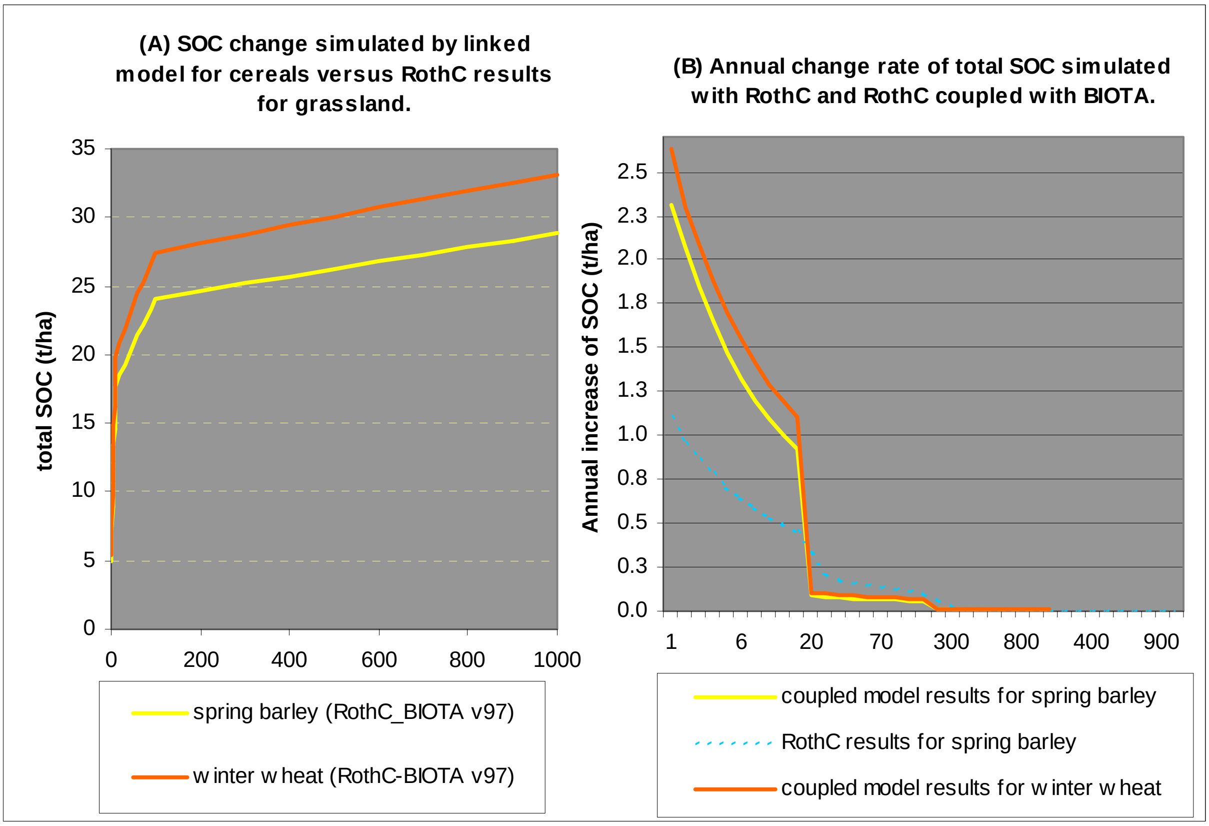

Figure 9-1: RothC-BIOTA v97 simulation of SOC dynamics in soils under winter and spring.

We compared the methods used by the models to reach soil equilibrium. The main difference was the rate of time-step change in the equilibrium run that was closely linked with decomposition and SOC accumulation (details are described in section 9.4.1).

We tested the link between BIOTA and ‘short-term’ RothC with corresponding principal designs. The new link was run for 1000 years. The test showed a great improvement in the annual rate of SOC change and confirmed the source of difference was in the principal design of equilibrium methods in both models (Figure 9-2). This difference was addressed as follows.

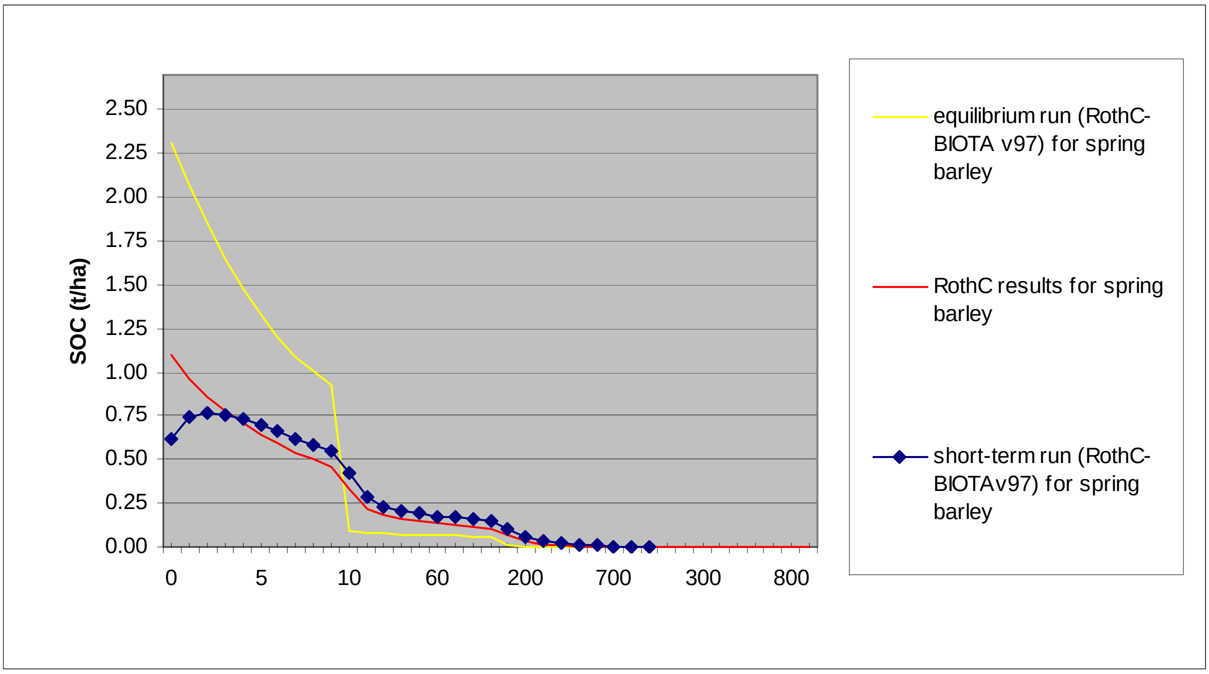

Figure 9-2 Annual rate of SOC change simulated by the coupled models with equilibrium and short-term methods.

Initial results of the tests revealed important methodological differences between RothC and BIOTA in reaching equilibrium state. RothC estimates decomposition of organic plant material and C content of the four active organic pools in a framework of an exponential time increase function ie. model results are output for years 1-10, 20, 30, 40,…100, 200, 300,..1000, 2000,…and 10000. This method is used in all versions of RothC (Coleman *et al.*, 1996) and it was originally designed to reduce the processing time. Currently, simulating decomposition processes at yearly time-steps, as is done in BIOTA, only marginally increases PCU run-time (running RothC this way for 10000 years takes only minutes in comparison with some detailed physical models with PCU run-time of hours and days). Close-coupling of RothC and BIOTA requires corresponding rates of plant growth (simulated by BIOTA) and decay of dead plant material in soil (RothC). In order to run the coupled model, the old equilibrium calculation routines were discarded and the ‘new approach’ taken was to adopt the method used by the ‘short-term’ RothC model. We initially retained the original assumption of soil reaching equilibrium after 10000 years. The model code was developed on the basis of the new GIS-RothC version 2003 (Smith *et al.*, 2005a, Smith *et al.*, 2005b), which was adopted for this project (more details in section 9.5). The new equilibrium approach was applied to the existing model subroutines (SETSIM and RUNC14 instead of previously used SETEQ and RUNTOEQ) as presented in Appendix 0.

After running the model for 10000 years it became apparent that soil organic pools reach equilibrium earlier than 10000 years; DPM in < 10 years, RPM in < 100, BIO in < 1000 and HUM < 3000 years. To reduce the PCU run-time a flexible algorithm was introduced to estimate the exact time for all the soil pools to reach equilibrium in site-specific conditions, based on no further increase in total SOC over a number of years. An algorithm was developed that monitors the change of SOC until it differs by less than 0.001 tC/ha in successive years, when the equilibrium state is reached. The threshold level is currently being tested.

9.4. Inclusion of spatial functionality adopted from GIS-RothCv03.

The new RothC-BIOTAv05 is based on the spatial model GIS-RothCv03, used to make spatial simulations for whole countries and continents (Smith *et al.*, 2005a, Smith *et al.*, 2005b). The code of the coupled plant-soil C model retains the spatial functionality, which will enable its applications to site and regional studies. We have developed a site version of this model (SITE_MODEL), which is linked to the regional RothC (GIS_MODEL). A transfer between the two model types is controlled in the MAIN model with a simple loop and variable *space* set to ZERO for this project. We also set LUCODE to agricultural land (=1), so that the same GIS-RothC routines could be applied directly to a site-scale. This is an advantage for future spatial applications of the coupled models, as no further code developments are necessary due to its multi-scale functionality. Further changes required for the site-scale code involved input of site-specific data in the form of a self-explanatory text file (INPUT_REF.TXT) presented in Appendix A.2. Model RothC-BIOTAv05 is called using the command line:

```
biotarothc -rothc <input_ref.txt> -biota biota.ini <crop.ini> -cruclimate
<climate.mon> -pladd <biota_pladd.txt>
```

A description of the command line is presented in Appendix A.3.

The command line was designed to test the link between the models and the effect of different climatic data sets. This will be retained in future for the user to decide on the best site-specific method. The options below give guidelines for using the different model functions.

9.4.1. Stand-alone RothC with ‘fitting-to-equilibrium’ option

This can be applied for the equilibrium runs, when there is measured SOC at equilibrium. It would enable the model results to be tuned to a specific equilibrium level. ‘Fitting’ option is switched automatically, when measured SOC > 0 in INPUT_REF.TXT.

This function can use site measurements of climate for individual years of the ‘short-term’ model. All the weather files need to be named in INPUT_REF.TXT.

9.4.2. RothC with BIOTA using site climate.

When measured monthly weather data are used, the model results can be considerably improved. The climate variables listed in <NAME>.MON are accordingly:

1. Fraction of wet days in a month (%)
2. Average Rain per wet day (mm)
3. Maximum temperature (°C)
4. Minimum temperature (°C)
5. Solar Radiation (MJ/m^2/day)
6. Relative Humidity (%)
7. Pan evaporation (mm)

9.4.3. RothC with BIOTA using CRU climate.

When there are no measured weather data other sources should be considered. We use the Climate Research Unit (CRU) data (http://www.cru.uea.ac.uk/cru/data/hrg.htm) that provide all the required inputs for both models. The Weather Generator with an in-built CRU dataset of BIOTA can be applied to estimate the input data given above, based on the site location in the U.K.

9.5. Initial evaluation and sensitivity analysis – a case study for spring barley.

The coupled model was run to equilibrium for the seven crops so far parameterised (Table 9-2) with Rothamsted climate. The climate input data, listed above in MON file, were based whenever possible on site measurements (temperature, pan evaporation). Those inputs were provided by `roth.dat`, weather input file to RothC that represents long-term monthly averages measured at Rothamsted weather station. The climate variables that were not available from the site source were obtained from CRU. This design of the monthly climate input ensured consistency throughout different simulation types for the testing of the coupled model.

There was a considerable improvement in total SOC simulated with RothC in the new coupled framework, which were comparable with measurements (section 9.3). RothC simulated higher SOC when soil carbon additions were estimated by BIOTA (Table 9-2). The overall increase in total SOC corresponded with larger monthly plant additions as estimated by BIOTA, compared to the inputs suggested by previous applications of RothC in which the soil carbon returns were estimated by fitting the model to match the measure soil carbon value. As expected, winter crop systems show higher rates of C accumulation than spring crops due to a longer growing season and hence a longer period during which the plants are adding carbon to the soil. For spring barley, however, the coupled model results at equilibrium (annual plant additions and total SOC) were ~ 25% higher than for winter barley. This was probably caused by much higher % debris input to soils estimated with DEBRIS Calculator (Table 9-1).

To evaluate the above simulations it was necessary to simulate C soil dynamics in continuous crop systems. RothC-BIOTA v05 was run for the Hoosfield Continuous Barley Experiment at Rothamsted in the south-east of England. The coupled model was applied to simulate C dynamics on un-manured plot. Spring barley has been grown on that plot since 1852, with the exception of 1913, 1934, 1943 and 1967 when it was fallow. Currently, the coupled model can simulate only continuous crops, with no land use change, so the fallow years could not be reflected in these simulations.

RothC-BIOTA was run for 1414 years before soil reached equilibrium SOC of 62 tC/ha (Figure 9-3). The model results were overestimated due to much higher monthly carbon inputs to the soil than suggested by fitting the stand-alone RothC to the measured SOC data. The BIOTA module estimated total plant additions in the growing season[1] at 1.73 tC/ha ('tuned' inputs to RothC suggest 0.66 tC/ha is required). At harvest[2], when 1.74 t C/ha of plant biomass was removed from the field, with the assumption that 50% of straw was removed with the grain, the remaining 1.16 tC/ha of plant material was added to the soil (straw, chaff and dead roots). This suggests a fresh yield of 5.12 t/ha, which was very close to the south-east average of 5.3 t/ha (MAFF, 1998).

Following the initial simulation, the coupled model was tested with different debris inputs during the growing season and at harvest. The following scenarios were simulated to test the sensitivity of the model to residue management:

1. spring barley inputs during the growing season with (a) 50% straw removed, (b) 75% of straw removed and (c) 100% of straw removed at harvest,

---

[1] *Growing season here refers to the period from the second month of plant growth to the last month but one.*

[2] *Harvest month with all the carbon inputs to the soil due to harvest*

2. spring wheat inputs during the growing season with (a) 50% straw removed, (b) 75% straw removed and (c) 100% straw removed at harvest.

Debris inputs during the growing season estimated with BIOTA for spring wheat were exactly the same as those suggested for Hoosfield spring barley by RothC (0.66 tC/ha). Scenario 2c (spring wheat debris return parameters with 100% of the straw removed) provided the best fit for Hoosfield, with annual debris input of 1.47 tC/ha and total SOC at equilibrium of 33.8 tC/ha (Figure 9-3). RothC-BIOTA was more sensitive to debris inputs during the growing season, with a proportional increase of C sequestration in the range 50% for the higher debris inputs (scenario 1c) (Table 9-3). That difference would increase by a further 30%, when half amount of straw was incorporated into soil at harvest (scenario 1a) (Table 9-3). In summary, model proved very sensitive to debris inputs, particularly at harvest.

Table 9-2 Annual inputs of dead plant matter into toil and total SOC after 1000 years of simulation with RothC and the coupled models.

	RothC		**RothC-BIOTA**	
crops	user-defined debris (tC/ha)	SOC (tC/ha)	debris calculated by BIOTA (tC/ha)	SOC (tC/ha)
winter wheat	0.92	26.3	2.24	63.0
spring wheat	0.52	14.2	2.54	47.2
winter barley	1.87	52.3	2.04	45.8
spring barley	1.83	42.2	2.89	63.9
winter oilseed rape	1.19	36.3	2.82	79.2
spring oilseed rape	1.08	24.4	2.77	58.3
field peas	0.74	17.9	1.82	40.0

The ‘short-term’ coupled model simulated SOC remaining at the equilibrium level, while the measurements suggested a slow loss of C caused by fallow years. This effect of land use change was simulated better by RothC with ‘fitted’ debris inputs. The coupled model cannot presently simulate that land use change, but the function is currently being developed.

Table 9-3 Sensitivity of the coupled model to different debris inputs.

Model run	**% straw removed at harvest**	**Annual plant additions (t C/ha)**	**SOC (t C/ha)**
Site measurement	-	-	33.8
RothC (site climate)	-	1.63	35.9
RothC (CRU climate)	-	1.63	35.9
Monthly debris additions defined for spring barley			
RothC-BIOTA	50%	2.89	61.9
RothC-BIOTA	75%	2.64	56.7
RothC-BIOTA	100%	2.39	51.5
Monthly debris additions defined for spring wheat			
RothC-BIOTA	50%	2.11	49.1

RothC-BIOTA	75%	1.79	41.9
RothC-BIOTA	100%	1.47	34.8

9.6. Current focus and future developments.

In the first instance we need to reconcile the BIOTA and RothC inputs so that a match to the measured SOC can be achieved. Overestimation of SOC stock at equilibrium could be due to:

a) total C in biomass being too high from BIOTA – we will test this by comparing to estimates of total biomass / C in biomass during the growing season – this will be done by harvest index and yield in the absence of measured data, but measured data will be sought,

b) too much C being returned from the crop biomass to the soil – this could be the result of incorrect relationships from SUNDIAL. This could be remedied by tuning the C return proportions calculated by DEBRIS so that the inputs match the measured SOC – this will only be done when we are sure BIOTA is not overestimating total crop biomass C.

More tests are being carried out at present, with the equilibrium threshold still being tested and the model still being developed to simulate crop rotations. All of the coding procedures need to be finalized soon to enable model evaluation in different cropping systems. The current model can simulate only continuous crops, while most long-term experiments are for various crop rotations. Further steps will involve detailed evaluation of the model in different agricultural systems with real climate inputs. Further parameters need to be derived from the literature to evaluate the current model parameters describing plant additions at harvest.

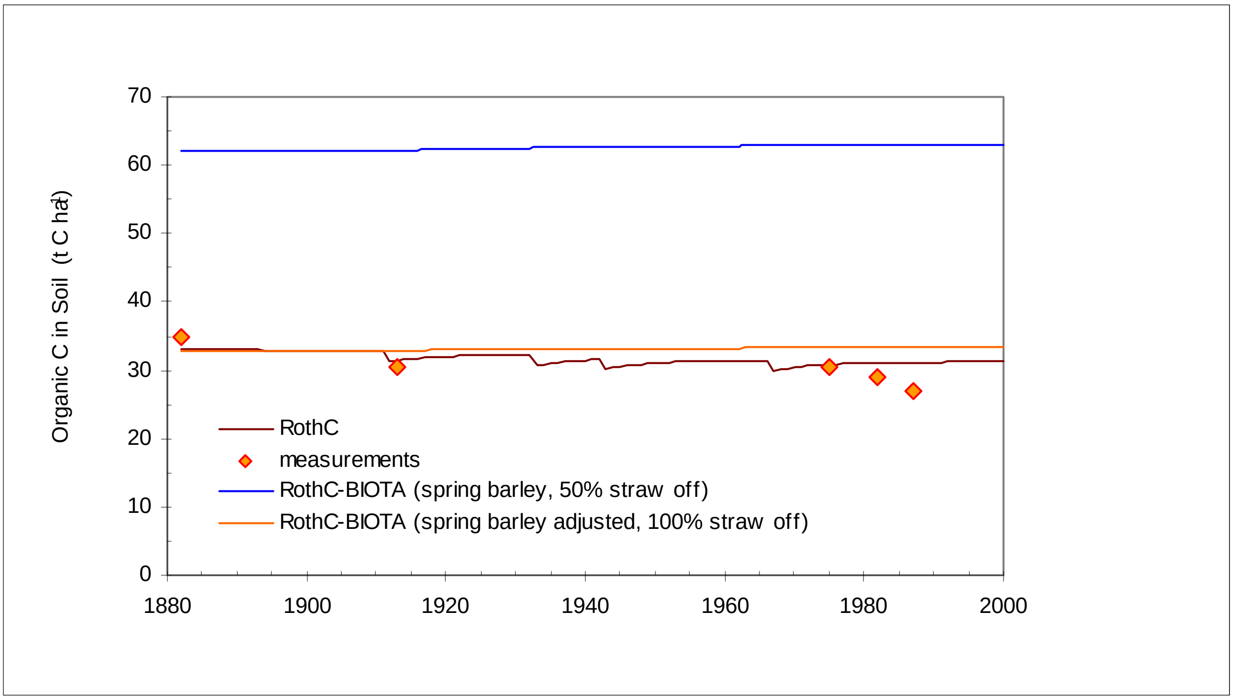

Figure 9-3 RothC ’short-term’ simulation results for Hoosfield, with and without BIOTA component.

9.7. References

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9.8. Appendices

A.1. New Equilibrium code.

```
      SUBROUTINE SETSIM(INYEAR)
C
C Sets up simulation
C
      IMPLICIT NONE
       INTEGER I,INYEAR
       REAL*8 T,TP,TF
C Common Blocks
C
      INCLUDE 'FILES.FOR'
      INCLUDE 'GIS.FOR'
      INCLUDE 'MAIN1.FOR'
      INCLUDE 'MOD1.FOR'
      INCLUDE 'MOD2.FOR'
       INCLUDE 'MOD4.FOR'
C
C Set values
C Type of simulation
       IF(EQUIL .EQ. 1) THEN
              ICAREQ=1     !Equilibrium run
       ELSE
              ICAREQ=0     !short-term simulation
       ENDIF
C No bomb effect
      IBOMB=1
C Starting year of simulation
      ISYEAR=INYEAR
C Run simulation for 200 years by default
c      NYEARS=200   !changed to 200 - GS 17/05/05
C Output results in last year
      IOUT=1
C Do not output monthly values
      MONCAR=0
C Start month = January
      MSTART=1
C
C Set fixed parameters for current land-use
C
      DO 10 I = 1,5
        FPLANT(I) = 0.0
 10   CONTINUE
      FFYM(1) = 0.49
      FFYM(2) = 0.49
      FFYM(3) = 0.0
      FFYM(4) = 0.0
      FFYM(5) = 0.02
      FDEC1(3) = 0.46
      FDEC1(5) = 0.54
      FPDEC1(4) = 0.46
      FPDEC1(5) = 0.54
      DECOMP(1) = 10.0
      DECOMP(2) = 0.3
      DECOMP(3) = 0.66
      DECOMP(4) = 0.66
      DECOMP(5) = 0.02
      FPLANT(1)=DRRAT/(1+DRRAT)
      FPLANT(2)=1/(1+DRRAT)
      T=FDEC1(3)+FDEC1(5)                   !WHAT ARE THESE USED FOR, JO?
      TP=FPDEC1(4)+FPDEC1(5)                !WHAT ARE THESE USED FOR, JO?
      TF=FPLANT(1)+FPLANT(2)                !WHAT ARE THESE USED FOR, JO?
```

```
C
C Set all active soil pools to zero ready for equilibrium run
C
      IF(ICAREQ .EQ. 1)THEN
             DO 660 I=1,5
                    SOIL(I)=0
660          CONTINUE
       ENDIF
       END
C
C Equilibrium run - new method using algorythm check
C
       CALL CALC1
       CALL BPCALC
       TOTCEQ=0
       TOTIN=0
       ISTARTYR=1
       ISTOPYR=10000

       last_TOTIN = -9999
       equilibrium_threshhold = 0.001

       do equilibrium_loop = 1, ISTOPYR, 100

              CALL RUNC14(TOTCEQ,TOTIN,equilibrium_loop,equilibrium_loop+100)

              if (abs(TOTC-last_TOTIN) .lt. equilibrium_threshhold) then
                     exit
              end if

              last_TOTIN = TOTC

       end do

!      End program if we didn't find equilibrium
       if (equilibrium_loop .eq. ISTOPYR+1) then
          write(*, *)'******* Could not find equilibrium after ', equilibrium_loop 1,
' years'
              stop
       end if

       TOTCEQ = TOTC

SUBROUTINE RUNC14(tceq,tcin,startyr,stopyr)
C
C
C  Running Carbon model with varying radiocarbon activity
C
C
      IMPLICIT NONE
C
C
C ** Common Statements
C
      INCLUDE 'GIS.FOR'
      INCLUDE 'MAIN1.FOR'
      INCLUDE 'MOD2.FOR'
C     INCLUDE 'MOD3.FOR'          !Used by GIS model only - ENABLE WHEN NEEDED
(02/2005)
      INCLUDE 'MOD4.FOR'
      INCLUDE 'MOD10.FOR'         !Replaces MOD3.FOR for SITE model (02/2005)
      INCLUDE 'TOTALS.FOR'
C
C
      REAL*8 tcin,tceq
       INTEGER*4 startyr,stopyr,NYPRINT,K,M,I
       MON=MSTART
      NYPRINT=0
C
C Do calculation for NYEARS years
```

```
C
      NYEARS=stopyr
      DO 20 K=startyr,stopyr
        IYEAR=IYEAR+1
        NYPRINT=NYPRINT+1
C
C Set this years weather data
C
        CALL GETENV(K)     !This replaced GETMET subroutine for GIS (02/2005)

C
C calculate (1) monthly rate modifying factors (2) set transition matrices
C
         CALL RATEF

         IF ((SPACE .EQ. 0) .AND. (IYEAR .EQ. 1)) THEN
           CALL INFOOUT
         ENDIF

         CALL SETMAT

C
C Do calculation for 1 year
C
        DO 10 M=1,12
             tcin=tcin+PLADD(MON,LUCODE)+FYMADD(MON,LUCODE)+tceq
          tceq = 0.0
C
C Calculate amount in soil carbon compartments for this month
C
          CALL MONAA
C
C If printing results, calculate totals ready for printing, and output results
C
          IF((NYPRINT.LE.MONCAR).OR.
     &      (MON.EQ.MEND.AND.IOUT.EQ.1).OR.
     &      (MON.EQ.MEND.AND.IOUT.EQ.2.AND.K.EQ.NYEARS).OR.
     &      (MON.EQ.MEND.AND.IOUT.EQ.2.AND.K.EQ.NYEARS/2))THEN
                    BIO = SOIL(3) + SOIL(4)
                    CO2 = tcin - TOTC
c                   ICOUNT = ICOUNT + 1        !Is this needed ? Jo (icount(2)?)
                    CALL PCAR
                    IF (space .EQ. 0 .and. ICAREQ .EQ. 1) CALL CQOUT
                    IF (space .EQ. 0 .AND. ICAREQ .eq. 0) CALL C14OT
           END IF
C
C Move on to next month
C
          MON=MON+1
          IF(MON.GT.12)THEN
            MON=1
            ISYEAR=ISYEAR+1
          END IF
C
C Save C in soil pools for output and calculating C after land use change
C
           DO 5 I=1,6
            IF(M.EQ.12)SOILC(K,I,LUCODE)=SOIL(I)
    5     CONTINUE
   10   CONTINUE
C
   20 CONTINUE
C
      RETURN
      END SUBROUTINE
```

A.2. Revised RothC input file.

```
Input data for RothC linked with BIOTA (RothC-BIOTA v05)

Site information:
clay % - 23.4
soil depth (cm) - 23.0
Measured C at equilibrium (t/ha) - 35.0
Year of measurement - 1882

Equilibrium run:
weather file   - roth.dat
land use file  - lmhfeq.dat

Short-term run:
weather       land use   nr_years
lines  - 1
roth.dat   lmtestsb.dat 200
```

A.3. Multi-functionality of simulation procedures.

Description of the command line:

-rothc - should be always selected for running the model, **<input_ref.txt>** file contains all input data and names of data files necessary for RothC (eg. climate data and land management data);

-biota – informs the model that BIOTA plant-module will run and estimate plant debris additions to soil instead of pre-defined plant additions in land management file, **biota.ini** is the BIOTA parameter file, **<crop.ini>** contains parameters defined for the current crop;

-cruclimate – informs the model (BIOTA) about the monthly climate input data **<climate.mon>** that are used by the Weather Generator to estimate daily weather data required by BIOTA**;**

-pladd – option that should be used when an output of plant debris, simulated by BIOTA, is needed, **<biota_pladd.txt>** is the name of the output file;

Section 10

Field measurements of carbon loss due to ploughing

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10. Field measurements of carbon loss due to ploughing

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May 2005

10.1. Introduction

Globally, it is estimated that around 50 Pg C have been emitted to the atmosphere from soils, following conversion of natural land to cultivated, agricultural land (Paustian *et al.*, 2000). The physical basis for this is that disturbance associated with intensive soil tillage increases the turnover of soil aggregates and accelerates the decomposition of aggregate-associated soil organic matter (SOM). However, the number of experimental data quantifying this effect are rather small, and there are no experimental data from the UK. The UK carbon inventory of sources and sinks due to land use change (Milne, 2003) requires this information, as it is based on a matrix of transitions between different land use types, and the fluxes arising in these transitions. Grassland soils represent a substantial part of the terrestrial carbon stocks in the UK, and there are potentially large losses when these are cultivated, either for conversion to arable land or for improvement of pasture. Here, our aim was to measure the losses of soil carbon following ploughing of a previously uncultivated grassland at a field site in south west Scotland.

Whilst the equilibrium soil carbon pool after any given land use conversion will depend on the system to which it is converted, here we focus on the losses which occur in the period of transition. To this end, the system was maintained in a bare state following ploughing by applying herbicide, and so our measurements represent an upper limit to the carbon loss from grassland when it is disturbed by ploughing.

The majority of this work has been reported previously (Levy *et al.*, 2004), but chemical analysis of the final soil samples was delayed by the move of CEH Merlewood to Lancaster, and were not available until October 2004. These samples were used to measure carbon stocks, and infer fluxes from the change over time. Here, we present the results of this method and compare it with the eddy covariance method.

10.2. Methods

Details of the field site and eddy covariance method are repeated here for convenience, but further details are given in Hargreaves *et al.*, 2001 and Levy *et al.*, 2004.

10.2.1. Field site and treatment

The site chosen for the study was at Poldean farm, near Moffat in south west Scotland (grid reference NT 111004 (N55:17:22, W3:24:08), altitude of 196 m). It is a livestock enterprise with extensive permanent pasture receiving fertiliser and manure inputs. The site was chosen on the basis of good meteorological conditions, an appreciable organic layer indicative of a long-term permanent pasture and a cooperative farmer.

An area of 200 x 200 m was fenced in November 2000 to exclude sheep and cattle. The experiment had been due to start in February 2001, but was delayed by the outbreak of foot and mouth disease on the farm, which prevented access for several months. By the time foot and mouth restrictions were lifted, winter weather and wet ground conditions delayed work until the following spring.

In April 2002, the fenced experimental area was first treated with glyphosate herbicide to kill existing vegetation. The field was then flailed in May 2002 to break up the surface and make ploughing easier. The site was ploughed, with considerable difficulty, on 5 June 2002, to a depth of 15 cm, although the heavy soil conditions meant that this was quite variable.

Two further treatments of glyphosate were applied on 15 July 2002 and 18 September 2002 to prevent regrowth of the vegetation. In the latter case, the application was delayed for around two weeks owing to heavy rain during the first few days of September, and this allowed some weed growth over the field before the glyphosate became effective.

The following year, a further treatment of glyphosate was applied in May 2003 and the area was cultivated by disking in June 2003. A final treatment of glyphosate was applied in September 2003. As in 2002, this application was delayed by unavailabilty of the contractor at harvest time, and some significant weed growth had taken place before the glyphosate became effective. The experiment was ended in April 2004, when instrumentation was removed and the field prepared for re-seeding. Throughout the period of the experiment, the land adjacent to the experimental area was kept in normal use, as pasture for sheep and cattle, and this is considered as a control area.

10.2.2. Soil carbon measurements

Before and after ploughing (in October 2000 and November 2003), soil samples were taken for analysis of carbon content. Eight sample plots were located in the experimental area, so as to be representative of the fetch area sampled by the eddy covariance measurements (Figure 10-1). Five cores were taken in each plot, and divided into 5cm depth intervals, up to 25 cm depth if possble. The same plots were sampled on both occasions. Samples were analysed at CEH Merlewood/Lancaster for organic carbon using Tinsley analysis, total carbon by loss on ignition, and bulk density. More details are provided by Jones *et al.*, 2001.

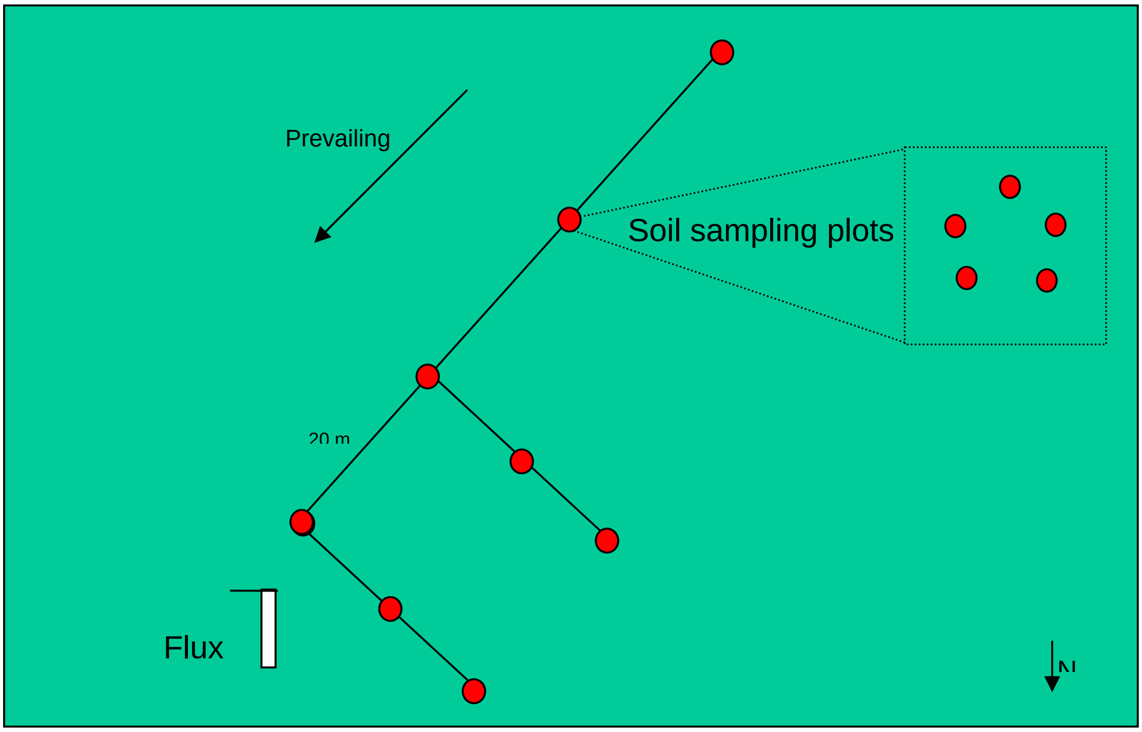

Figure 10-1 Layout of soil sampling points within the experimental area at Poldean Farm. Points were arranged to be in the prevailing upwind direction of the eddy covariance flux tower, and clustered near the tower, so as to be representative of the fetch area sampled by the eddy covariance measurements.

10.2.3. Eddy covariance measurements

A micrometeorological approach, eddy covariance, was used to make near-continuous measurements of the surface exchange of carbon dioxide (CO_2) over the experimental area and the control area. The eddy covariance flux measurement system was sited on the NE edge of the experimental area, so that the most common, south-westerly wind direction would allow measurements to be made over the ploughed area. Northerly winds would allow measurements to be made over the control area. Full details of the instrumental techniques may be found in Hargreaves *et al.*, 1998,Hargreaves *et al.*, 2001, and Hargreaves *et al.*, 2003. In brief, the net flux of CO_2, F_c, is given by:

$$F_c = \overline{w'\chi} \qquad \text{eq 10-1}$$

where *w*' is the instantaneous deviation of the vertical windspeed from the mean, and χ is the instantaneous deviation of the CO_2 concentration from the mean. The three components of windspeed were measured at 20 Hz by a Metek ultrasonic anemometer (Model USA1, METEK GmbH, Elmshorn, Germany), mounted at a height of 1.75 m. Air was sampled continuously from a point close to the anemometer down stainless steel tubing (0.25 inch diameter, Dekeron Corp. Illinois, USA) at a flow rate of 5 l /min. CO_2 and H_2O concentrations were measured by an infra-red gas analyser (IRGA)(LI-6262, Licor Corp., Nebraska, USA) with a response time 6.3 Hz. Analogue outputs from the IRGA were passed to the ultrasonic anemometer where they were digitised. A laptop PC, running a LabView software package, logged the data from these instruments and carried out the eddy covariance calculations.

A Campbell 23X datalogger controlled switching of the power supply, and provided remote telemetry via the mobile telephone network. Supporting meteorological measurements included solar radiation, photosynthetically active radiation (PAR), soil and air temperature, relative humidity, soil moisture, and rainfall. Power was supplied by a Rutland model 910-3 Furlmatic wind turbine and four 60W solar panels with a total area of 2 m^2. These charged an array of deep-cycle sealed lead-acid batteries with a total capacity of 700 Ah. The 23X datalogger controlled power consumption by switching off sample pumps and the Licor gas analyser when meteorological conditions were unsuitable for eddy covariance measurements, or battery voltage was too low. Otherwise the system was kept running from May 2002 to April 2004, with occasional breaks for instrument maintenance or lack of power.

In order to produce an estimate of the long-term carbon balance, gaps in the measurement data were filled using standard methodology (Aubinet *et al.*, 2000). This involved fitting simple models based on light and temperature responses to the measurement data, and using the fitted models to interpolate the missing values. For daytime values over the control area, data were fitted to the following model:

$$F_{NEE} = F_{RE_{DAY}} - F_{GPP_{OPT}} \left(1 - \exp\left[\frac{a' S_t}{F_{GPP_{OPT}}} \right] \right) \qquad \text{eq 10-2}$$

where F_{NEE} is the net ecosystem exchange of CO_2 ,F_{REDay} is the daytime ecosystem respiration rate, F_{GPPopt} is the gross primary production, S_t is the solar radiation flux and a’ is a fitted parameter. Night-time fluxes, and all fluxes over the ploughed area were fitted to the model:

$$F_{NEE} = d \exp(eT_a) \qquad \text{eq 10-3}$$

where d is a fitted parameter and T_a is air or soil temperature. Where linear regression gave a better fit to the data, this was used instead.

10.3. Results

10.3.1. Soil carbon measurements

All the points in Figure 10-2 fall below the 1:1 line, indicating a clear decrease in soil carbon after ploughing. Figure 10-2 also shows that there is considerable spatial (between-plot) variability, which is consistent over time. This was therefore accounted for statistically by including ‘plot’ as a factor in an analysis of variance.

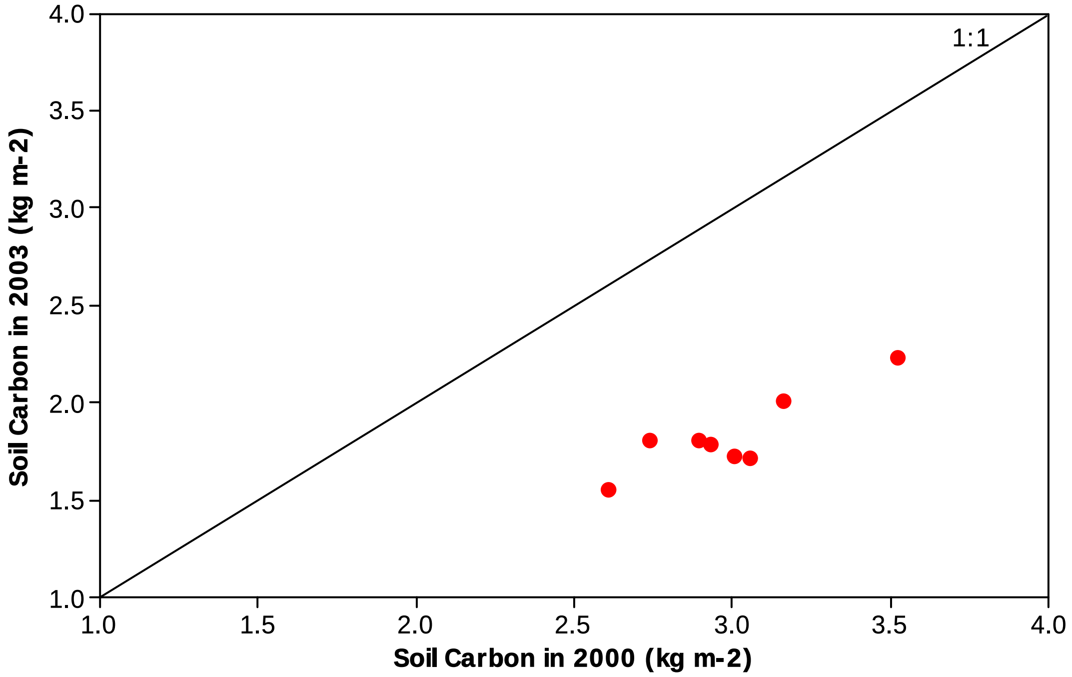

Figure 10-2. Scatter plot of soil carbon measured before ploughing in October 2000 versus values measured after ploughing in November 2003, at the eight sampling plots. Points are the mean of the five cores within each plot.

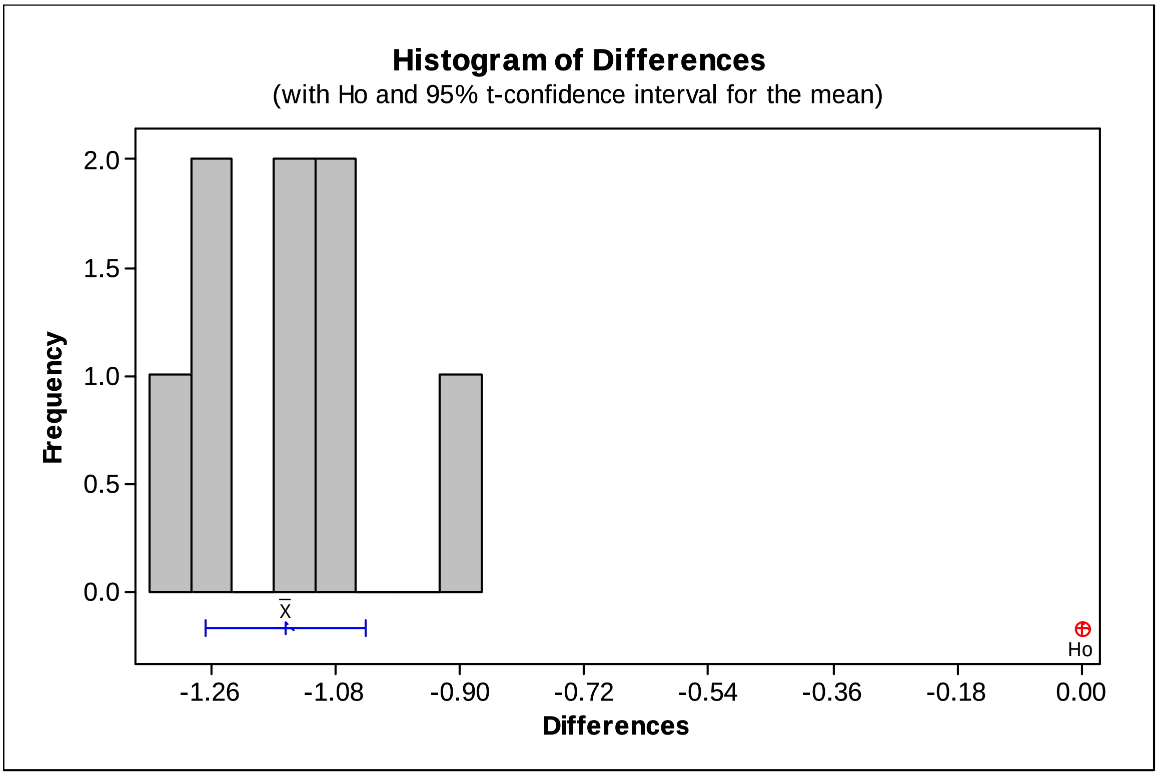

Figure 10-3 Histogram of the difference in plot means for soil carbon before and after ploughing, at the eight sampling plots. Bars are the mean of the five cores within each plot. The null hypothesis of no difference, H_o, lies outwith the 95 % confidence interval of the measurements.

Table 10-1 Analysis of Variance table for the effect of ploughing (represented as 'Year' – whether before (2000) or after ploughing (2003)) on soil carbon, using adjusted SS for tests. Plot was included as a random factor to account for spatial variation across the field.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	1	26.5617	26.5617	26.5617	312.25	0.000
Plot	7	3.8856	3.8856	0.5551	6.53	0.000
Error	71	6.0396	6.0396	0.0851		
Total	79	36.4868				

The results in Figure 10-3 and Table 10-1 show a highly significant decrease in soil carbon after ploughing ($p < 0.001$). The magnitude of this decrease is 1.15 kg C m^{-2} or 39 % of the initial value (or 0.80 kg C m^{-2} y^{-1} or 27 % y^{-1}, counting 528 days between the date of ploughing and the final soil sampling).

10.3.2. Comparison with eddy covariance measurements

Figure 10-4 shows a comparison of estimates of carbon emission from the ploughed field from the two methods. This shows that the direct measurement of soil carbon stock change gives a higher estimate than the eddy covariance flux measurements. Whether this difference (0.42 kg C m^{-2}) can be judged statistically significant is not simple, as rigorous confidence intervals can only be calculated for the soil carbon stock measurements.

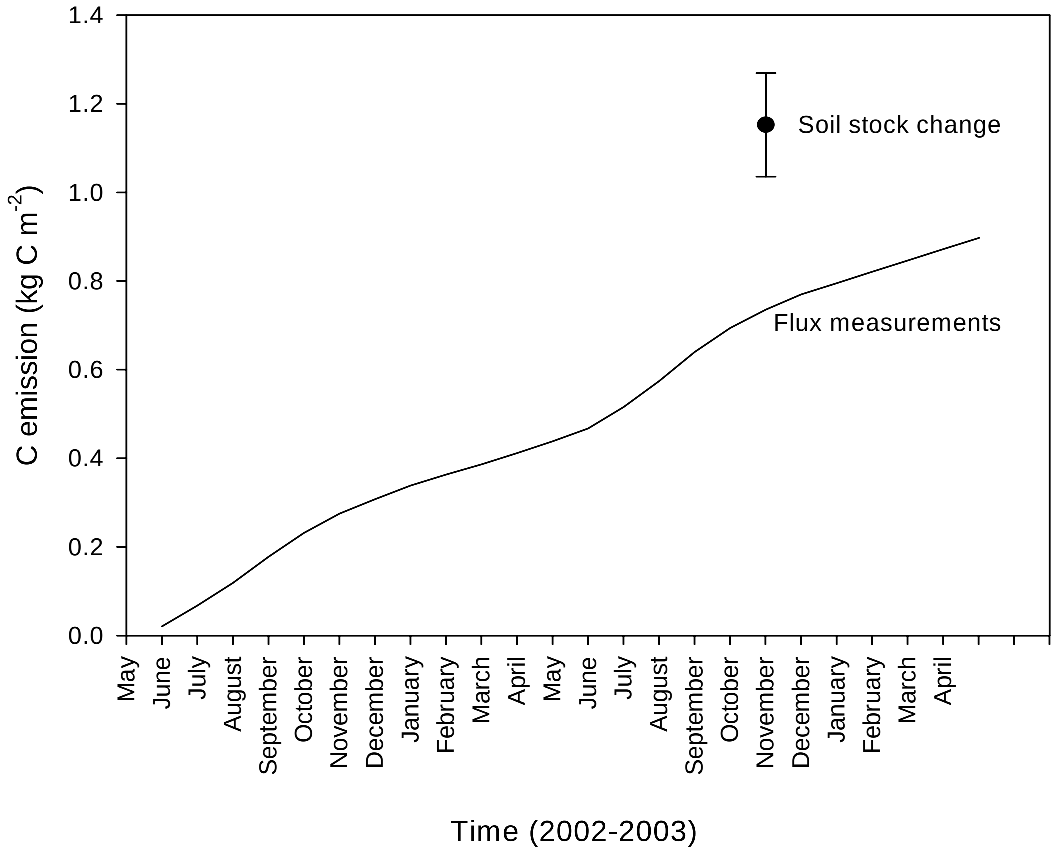

Figure 10-4 Comparison of estimates of carbon emission from the ploughed field from changes in soil stocks and by eddy covariance flux measurements. Error bars show the 95 % confidence interval in the change in soil carbon, based on the variability between plots.

10.4. Discussion

The discrepancy between the two methods raises the questions of which is more reliable, and should give the more accurate estimate of the true change. The soil stock change method has the advantage of being based on relatively simple chemical analyses and classical sampling methods, which permit the uncertainty to be estimated. The main disadvantage of this method is that natural spatial variability in soils usually overwhelms any signal of interest, such that either a very large sample size is needed to detect a statistically significant difference. Here, we largely overcome this problem by perturbing the system to such a large extent that the change is detectable with a reasonable sample size. The eddy covariance method has the advantage of directly measuring the flux of interest and integrating this over a large area. The problem of spatial variability is therefore avoided. The main disadvantages are that the random error in the estimate is not easily quantified (though it should be small), and there may be systematic errors related to failure to account for fluxes at very high and very low frequencies. This arises because (1) fluxes at frequencies higher than the slowest instrument response time (~0.5 s for the Li-Cor gas analyser) are not measured, and (2) fluxes at frequencies lower than the averaging time (15 mins) are not measured. Methods exist to correct for these ‘flux losses’ but this is still an area of ongoing research. Given that there are reasons to expect the eddy covariance measurements to underestimate the flux, whilst the stock change method is subject mainly to random error, we would suspect the latter to be the more accurate estimate in this instance. With a less dramatic experimental manipulation, the stock change method would be unlikely to detect a significant change without a very large sample size.

Table 10-2 shows an addition to the equivalent table in Levy *et al.*, 2004, using the soil stock change data, comparing the greenhouse warming potential (GWP) of the three gases measured. Using this higher flux estimate, CO_2 becomes an even more dominant term. CH_4 and N_2O fluxes are only significant when considered as a fraction of the total in the unploughed area, where the CO_2 source is very small, but the absolute numbers are relatively negligible.

Table 10-2 Greenhouse warming potential (GWP) of the three gases measured at Poldean in the ploughed field. GWPs are calculated in terms of CO_2 equivalents, assuming standard IPCC values for the multiplicative factors for N_2O and CH_4.

	t CO_2 ha^{-1} yr^{-1}	t N_2O-N ha^{-1} yr^{-1}	t CH_4-C ha^{-1} yr^{-1}	GWP: t C-CO_2 ha^{-1} yr^{-1}
CO_2 Exchange	8.02			8.02
N_2O Exchange		0.0006		0.19
CH_4 Exchange			0.003	0.08
Total GWP				8.29

Figure 10-5 shows a comparison of measured carbon emissions with predictions from the existing inventory model, in which the litter input after ploughing is varied between 0.0 and 0.75 of that before ploughing. The inventory model is based on a single exponential decay function. The predictions where litter input are zero are very close to the measured values, suggesting that the model represents these conditions reasonably well. It would be expected that the measured values would lie somewhat below the litter input = 0 line, as some litter will have entered the soil, mainly after weed control treatments, so the model is underestimating the emissions to some extent.

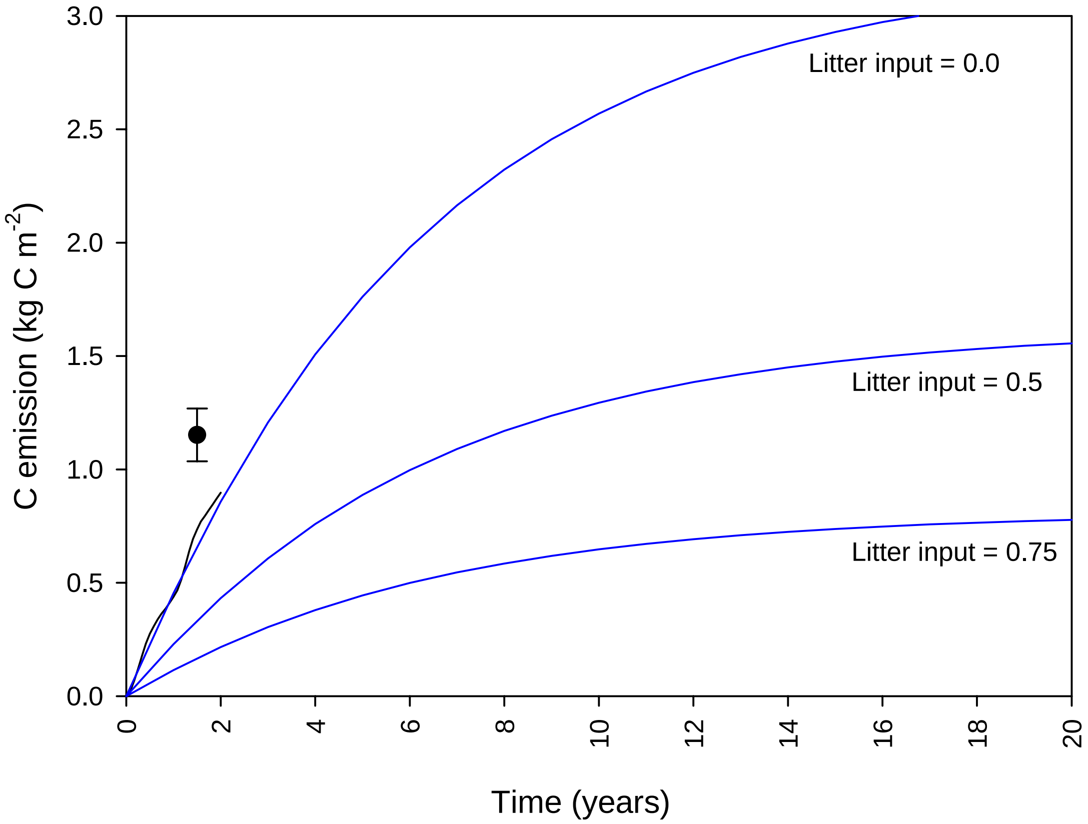

Figure 10-5 Comparison of measured carbon emissions (as in Figure 10-4) with existing inventory model predictions. Predictions are shown in which the litter input after ploughing is 0.0, 0.5 or 0.75 of that before ploughing.

The main disadvantage of our approach is the lack of further appropriate control treatments. To discern the affect of ploughing *per se*, we would need an unploughed treatment with herbicide. The difference between the flux from this and the ploughed treatment would allow us to quantify the effect of ploughing independently of the effect of herbicide. However, this would require twice the area of land to be taken out of production for the experiment (to achieve an appropriate fetch for micrometeorological measurements), and be twice as expensive in compensation payments. Given limited funds, we did not have such a treatment, meaning that our results are representative of what actually commonly happens in practice (over the first few months), but their interpretation in terms of the effects of ploughing and herbicide is more difficult. To explicitly separate these effects, we propose a plot-scale experiment to detect the effect of cultivation on soil organic carbon content.

Recent work (Smith & Conen, 2004, Li *pers. comm.*) suggests that the increase in N_2O emissions in “no-till” agriculture outweighs the effect of carbon sequestration, in terms of Global Warming Potential (GWP). It is therefore of interest to include measurements of N_2O emission in such studies. Results from the Poldean experiment showed no significant effect on N_2O emission, but were very variable and a higher sampling density would be needed to detect significant differences.

Here, we propose a plot-scale experiment with a Latin Square design, located close to CEH Bush, at a nearby SAC farm (House O’ Muir). Measurements will be made of:

- Initial and subsequent soil carbon stocks, by loss on ignition (LOI),

- Soil CO_2 fluxes using a Licor 6200 or EGM gas analyser,

- N_2O fluxes using both a static chamber method and possibly also using an automated sampling chamber, analysed on a GC.

Power analysis based on the variability in soil samples at Poldean suggests that 26 replicates per treatment would be needed to detect a change of 0.25 kg C m^{-2} (half the annual change observed at Poldean). With three treatments, this gives 78 experimental units. Figure 6 shows an outline of the proposed experimental design, with 81 units. The method proposed method is as follows:

1. June 2005.

An 11 x 11 m area of grassland will be harvested and sprayed with ‘Roundup’ herbicide. Herbicide applications will be repeated as necessary over the experiment to prevent vegetation regrowth.

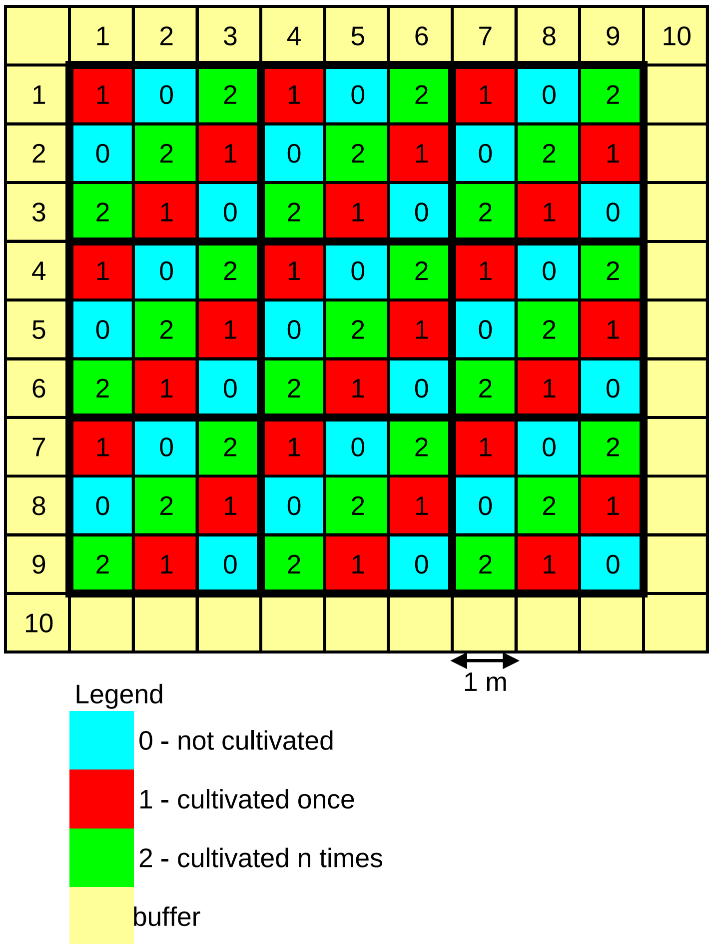

Figure 10-6. Replicated Latin Square experimental design, showing 9 x 9 m area with three treatments applied to 1 x 1 m plots in a 3 x 3 Latin Square, repeated 3 x 3 times.

2. July 2005

The outermost 1 m will be reserved as a buffer zone to reduce edge effects from surrounding vegetation. The inner 9 x 9 m will be divided into 1 m plots. Several soil cores will be taken from each plot, down to 15 cm depth and bulked. This will provide one sample from each of the 81 plots. These samples will be analysed by LOI to give initial soil carbon content. A sub-sample of material will be sent to CEH Lancaster for chemical analysis, to calibrate the LOI – C content relationship. Fluxes of CO_2 and N_2O will be made on all 81 plots using dynamic and static chambers, respectively.

3. July 2005.

The 81 plots will be allocated to three treatments:

0. control (uncultivated),

1. cultivated once, and

2. cultivated n times

and arranged in nine 3 x 3 Latin Squares (Figure 10-1). Treatment 1 will be cultivated once (only), in June 2005, to a depth of 15 cm using a rotovator. Treatment 2 will be cultivated at the same time and several times over the experiment to maximise the treatment effect, even though it is not realistic of normal practice.

4. July 2005 and bi-monthly until April 2006

Fluxes of CO2 and N2O will be made on all 81 plots at bi-monthly intervals. Treatment 2 will be re-cultivated ~quarterly.

5. April 2006

Soil cores will be taken from each of the 81 plots and soil carbon content measured by LOI (with a sub-sample going to CEH Lancaster for chemical analysis), as in May 2005.

Statistical analysis

The change in soil carbon content over the experiment will be compared in the three treatments using a one-way analysis of variance. Because the Latin Square design ensures that all treatments are distributed across the experimental area in a balanced way, this can be analysed as a simple ANOVA with no block effect, as a full Latin Square, or with intermediate degrees of blocking, depending on the spatial variation observed in the data. Dummy ANOVA tables using random data are given below for the cases of either (i) no blocking or (ii) accounting for row and column effects.

(i)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Cultivation	2	1.522	0.761	0.76	0.471
Residual	78	78.000	1.000		
Total	80	79.522			

(ii)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Rows stratum	8	442.516	55.314	55.31	
Columns stratum	8	3.407	0.426	0.43	
Cultivation	8	8.984	1.123	1.12	0.362
Residual	56	56.000	1.000		
Total	80	510.907			

CO_2 and N_2O fluxes will be analysed in the same way, with the exception that a time series of data should be available at ~bi-monthly intervals. A repeated measures ANOVA technique may be applied to account for changes with time.

10.5. References

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10.6. Acknowledgements

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Section 11

Carbon Balance of Peatlands at Moor House

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11. Carbon balance of Peatlands at Moor House

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May 2005

11.1. Introduction

Upland peats represent the largest store of carbon in UK ecosystems. Carbon balance of these peatlands will be affected by changes in land use (particularly grazing pressure and management for grouse) as well as changes in climate, CO_2 concentration and nitrogen deposition. These peatlands have the potential to act as a major source or sink for carbon if they are degrading or agrading, but their current status is unknown. This work will quantify the carbon balance of an upland peat catchment at Moor House, Teesdale, typical of much of upland peat areas in the UK. Whilst some previous studies have measured the net atmospheric exchange of carbon over peatland sites, the results cannot be easily interpreted as the complete carbon balance, as a substantial fraction may be lost through stream water (as dissolved and particulate organic carbon (DOC and POC), dissolved inorganic carbon (DIC), dissolved gases, as well as fluxes of gases from stream water (evasion)). The unique aspect of this work will be to measure all components of the carbon budget, including atmospheric and fluvial fluxes, at a site where long-term records are available.

Predicting changes in the store of carbon within the soil resulting from changes in land use or climate requires a process-based model. Historically, such models have been developed for conditions typically encountered in intensive agricultural systems, such as arable crops and improved pasture, where mineral soils predominate. However, much of the soil carbon within the UK is found in highly organic soils, in upland areas where land management is minimal, and the climate is cool and wet. Existing soil models (such as RothC) fail to capture the dynamics of carbon in these highly organic soils, largely because of differences in soil chemistry, soil fauna and microbial community composition**.** Basic measurements of the model parameters (turnover rates, pool sizes) and variables (carbon fluxes in, out & between pool) necessary for validation are lacking. Here, we aim to make the field measurements required for developing and validating a process-based model of carbon dynamics under these conditions.

The atmospheric component of the budget will be obtained by measuring the net exchange of CO_2 by eddy covariance, with a flux footprint covering ~1 km. The fluvial components will be obtained by measuring stream water concentrations of DOC, POC and DIC together with discharge rates, in collaboration with the Environmental Change Network, CEH Lancaster. Evasion of gases from stream water is currently being investigated by Dr Mike Billett, CEH Edinburgh. The fluxes of CO_2 and CH_4 from both vegetated peat will be measured using chamber methods. These chamber methods can also be used to do manipulative experiments, deriving responses to light, temperature, soil moisture, and to investigate spatial heterogeneity related to recovery from burning of patches for grouse management. The following inputs and outputs to the system will be quantified, at varying time resolutions, over a two-year period:

Inputs:

- $CO2$ uptake from the atmosphere by plant photosynthesis;
- input of DOC and inorganic carbon in precipitation;

Outputs:

- efflux of CO_2 to the atmosphere resulting from plant and soil respiration;
- fluvial outputs of DOC, POC, DIC and dissolved gases;
- efflux of CH_4 to the atmosphere resulting from methanogenic microbial activity.

These measurements will be integrated to construct a complete carbon budget over the two -year period. Mechanistic modelling based on these measurements and the existing records will be used to predict the longer term changes in carbon storage within this catchment. The Moor House site is part of the Environmental Change Network, and many long-term monitoring studies have been made on the catchment since the International Biological Programme in the 1970s, and as a flagship site of TIGER in the 1990s. Long-term records are available for meteorology, hydrology, stream water chemistry and vegetation. These will be used to extrapolate estimates of the carbon balance over several decades.

11.2. Methods

11.2.1. Field site

The site chosen for the study is at Moor House in the North Penines (grid reference NY745335, altitude of 580 m, Figure 11-1). This site lies within the Moor House - Upper Teesdale National Nature Reserve, which is also a UNESCO Biosphere Reserve and a European Special Protection Area. The site is an area of extensive blanket peatland and upland grasslands. The land is owned by English Nature, and provides free range common grazing (mainly sheep) for villages in the Eden Valley. Research has been undertaken on the site since the 1930s by Universities and Institutes. A wide range of issues have been previously been investigated, especially the impact of land use change, climate change and the deposition of pollutants, and the functional processes of blanket peatland and streams. In the 1960s and 1970s the area was intensively studied as part of the International Biological Programme and in the 1990s as a flagship site of the Terrestrial Initiative in Global Environmental Research (TIGER). Further background information is available at http://www.ecn.ac.uk/sites/moorh.html. The site was chosen because of the large body data from historical and ongoing research, the co-operative land owner, and the fact that the area is typical of much of upland peat areas in the UK. The particular location for the flux tower was chosen as a good compromise between suitably level topography, representativeness of the vegetation, and vehicle access (Figure 11-2).

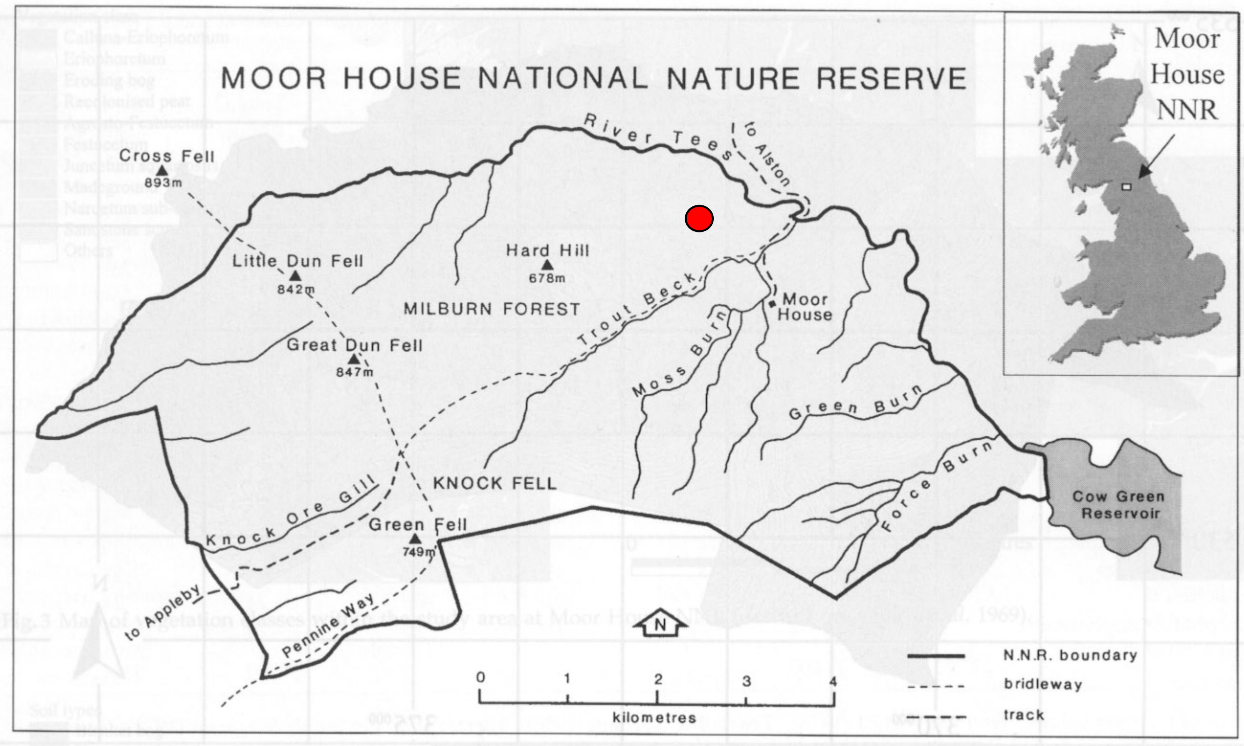

Figure 11-1 Location of the Moor House National Nature Reserve within the UK (inset) and location of the eddy covariance measurement tower within the reserve (red circle).

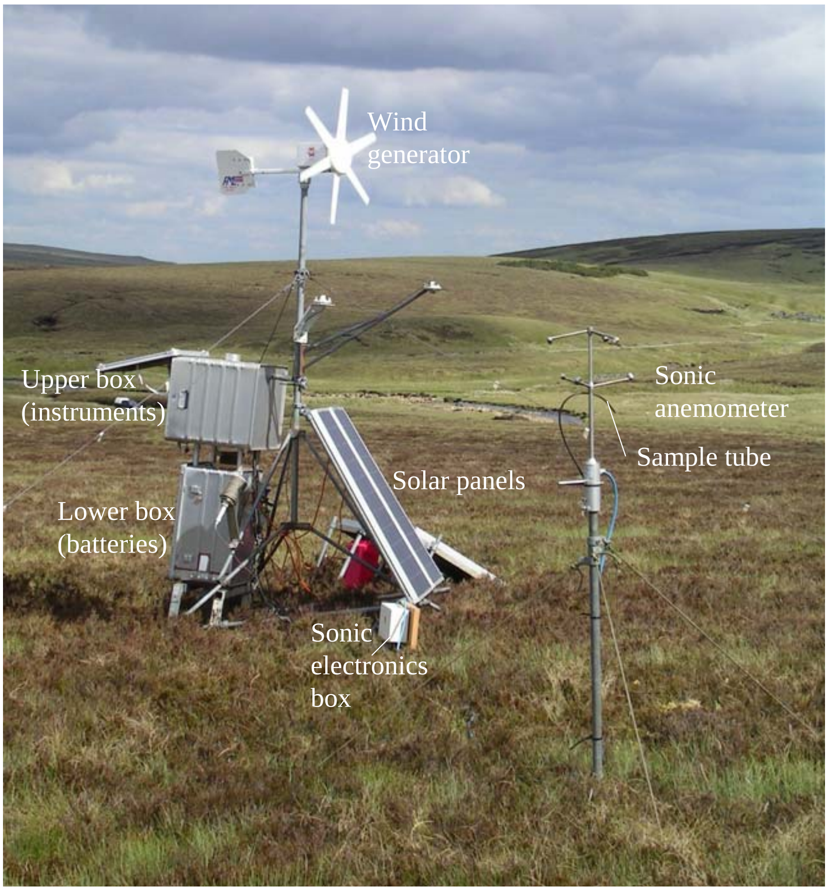

Figure 11-2 Eddy covariance equipment at the Moor House site, looking south-east.

11.2.2. Eddy covariance measurements

A micrometeorological approach, eddy covariance, is used to make near-continuous measurements of the surface exchange of carbon dioxide (CO_2) over the site. Equipment was installed between 17-25 June 2004. The eddy covariance flux measurement system was sited to the north of Trout Beck and the east of Hard Hill, on a gently sloping area of blanket peat (Figure 11-2). With the prevailing south-westerly wind direction measurements are made over one of the ECN soil sampling areas, where soil carbon is measured every five years. Full details of the instrumental techniques are as in Hargreaves *et al.*, 1998 and Hargreaves *et al.*, 2003. In brief, the net flux of CO_2, F_c, is given by:

$$F_c = \overline{w^{'}\chi} \qquad \text{eq 11-1}$$

where w' is the instantaneous deviation of the vertical windspeed from the mean, and χ is the instantaneous deviation of the CO_2 concentration from the mean. The three components of windspeed are measured at 20 Hz by a Metek ultrasonic anemometer (Model USA1, METEK GmbH, Elmshorn, Germany), mounted at a height of 1.75 m. Air is sampled continuously from a point close to the anemometer down stainless steel tubing (0.25 inch diameter, Dekeron Corp. Illinois, USA) at a flow rate of 5 l /min. CO_2 and H_2O concentrations are measured by an infra-red gas analyser (IRGA)(LI-6262, Licor Corp., Nebraska, USA) with a response time 6.3 Hz. Analogue outputs from the IRGA are passed to the ultrasonic anemometer where they are digitised. A laptop PC, running a LabView software package, logs the data from these instruments and carries out the eddy covariance calculations.

A Campbell 23X datalogger controls switching of the power supply, and provides remote telemetry via the mobile telephone network. Supporting meteorological measurements include solar radiation, photosynthetically active radiation (PAR), soil and air temperature, relative humidity, soil moisture, and rainfall. Power is supplied by a Rutland model 910-3 Furlmatic wind turbine and four 60W solar panels with a total area of 2 m^2. These charge an array of deep-cycle sealed lead-acid batteries with a total capacity of 700 Ah. The 23X datalogger controls power consumption by switching off sample pumps and the Licor gas analyser when battery voltage is too low. Otherwise the system has been kept running from June 2004 to date, with breaks for instrument maintenance or lack of power.

In order to produce an estimate of the long-term carbon balance, gaps in the measurement data are filled using standard methodology (Aubinet *et al.*, 2000). This involves fitting simple models based on light and temperature responses to the measurement data, and using the fitted models to interpolate the missing values. For daytime values over the control area, data are fitted to the following model:

$$F_{NEE} = F_{RE_{DAY}} - F_{GPP_{OPT}}\left(1 - \exp\left[\frac{a'S_t}{F_{GPP_{OPT}}}\right]\right) \qquad \text{eq 11-2}$$

where F_{NEE} is the net ecosystem exchange of CO_2 ,F_{REDay} is the daytime ecosystem respiration rate, F_{GPPopt} is the gross primary production, S_t is the solar radiation flux and a' is a fitted parameter. Night-time fluxes are fitted to the model:

$$F_{NEE} = d\exp(eT_a) \qquad \text{eq 11-3}$$

where d is a fitted parameter and T_a is air or soil temperature. Where linear regression gives a better fit to the data, this is used instead.

11.3. Results and Discussion

Figure 11-3 shows the response of the CO_2 flux to photosynthetic photon flux density (ie. 'light') in mid-summer 2004. This shows the typical form of response, with a near-linear increase in the flux up to around 400 µmol m-2 s-1 PPFD, and reaching saturation at around 1000 µmol m-2 s-1 PPFD. The net fluxes are relatively low compared with forest and agricultural ecosystems, where maximum fluxes are commonly in the range 10 to 20 µmol m-2 s-1. This is probably because of the lower LAI, the mature state of the vegetation, and the environmental limitations imposed at the site.

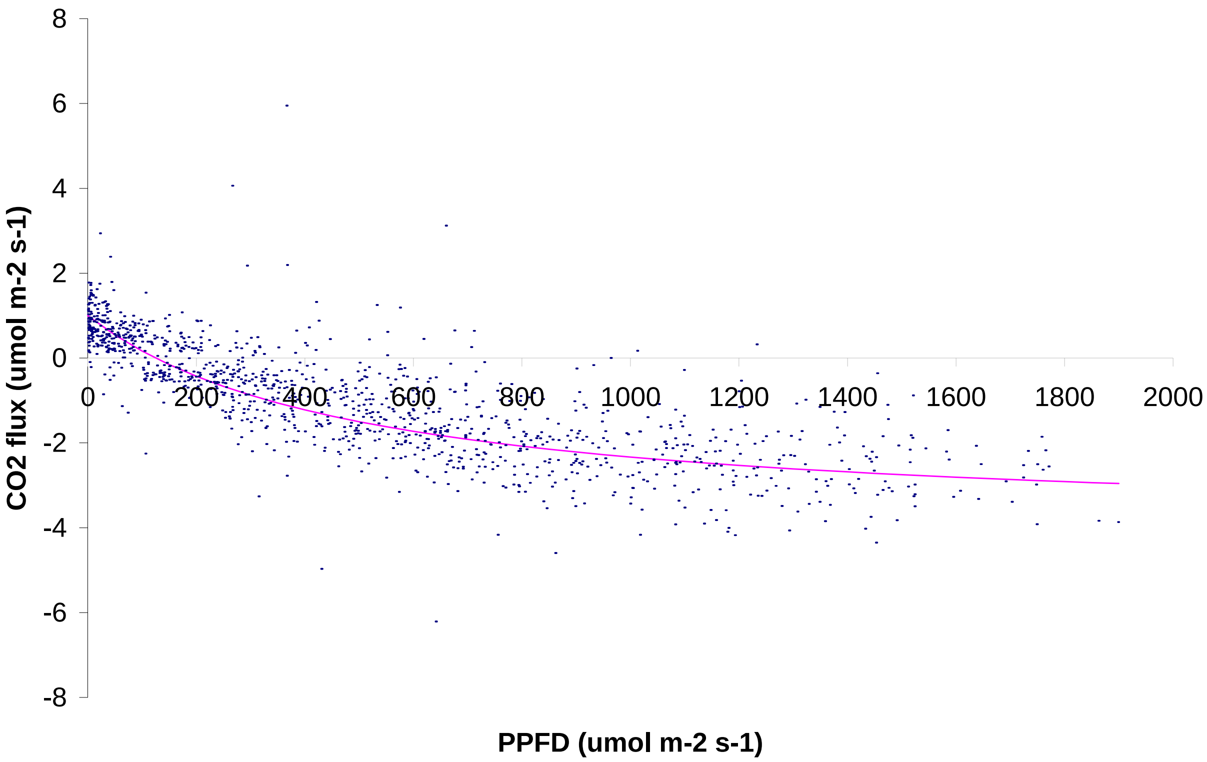

Figure 11-3 Scatter plot of CO_2 flux versus photosynthetic photon flux density, showing the 'light' response curve. Points are the mean over fifteen-minute intervals for the period 25 June to 20 July 2004, filtered to remove spikes and outliers. The curve shows Equation 11-2 fitted to the data. All Figures use the micrometeorological sign convention, whereby positive represents an emission and negative represents uptake at the surface.

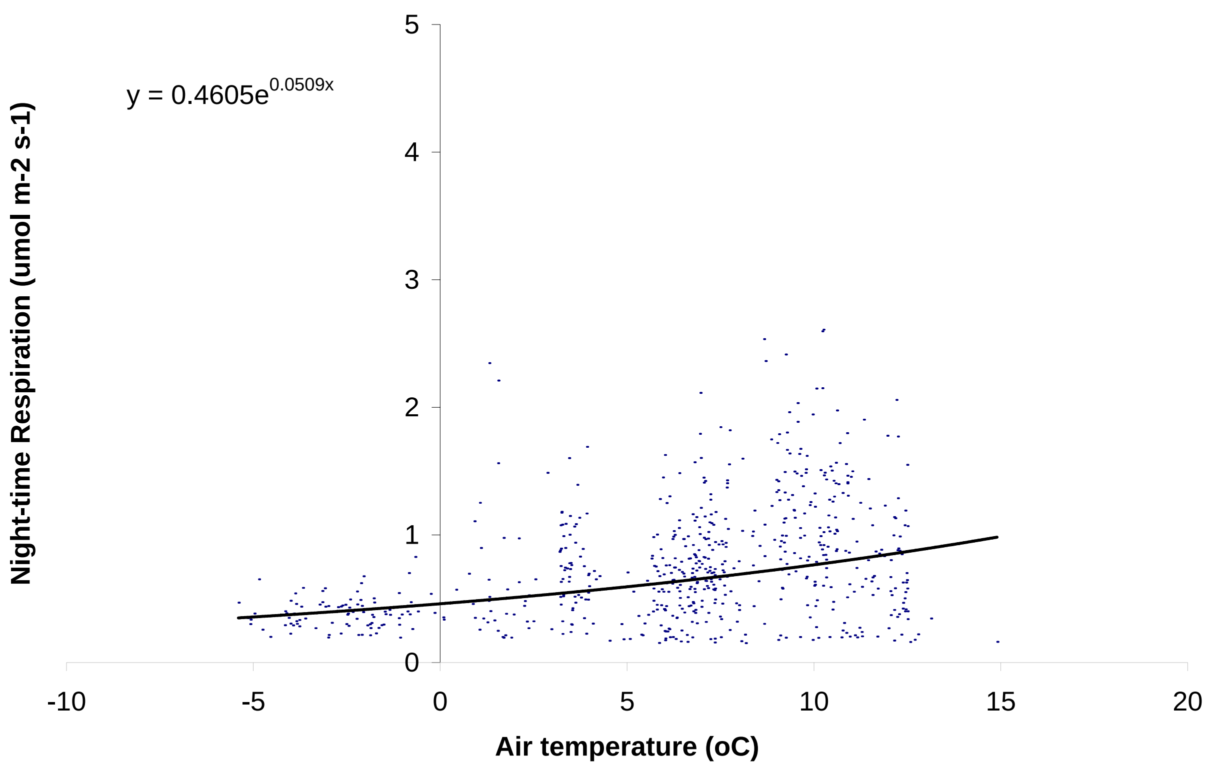

Figure 11-4 Scatter plot of the night-time CO_2 flux versus air temperature. Points are the mean over fifteen-minute intervals, for the whole of the 2004 data set, with several spikes removed. The curve shows Equation 11-3 fitted to the data.

Figure 11-4 shows the response of the night-time CO_2 flux (ie. ecosystem respiration) to temperature. There is much more scatter in this relationship, partly because the temperature range is not very large, seasonal variability is included here, and the low windspeeds at night make the eddy covariance technique less reliable. However, a general increase with temperature is discernible, and fitting the exponential model to the data is not unreasonable. This gives a fitted 'Q_{10}' value of 1.66.

Figure 11-5 shows a the observed CO_2 flux together with estimates from the gap-filling model. This shows that the gap-filling model accounts for much of the variation in the measurements, although there are always a number of outlying data points which have to be assessed and judged to be errors or not. Figure 11-6 shows the provisional cumulative CO_2 flux for the ~one-year period (18 June 2004 to 13 June 2005), based on the eddy covariance measurements where available and using the gap filling model elsewhere. This gives an annual net flux to be a small source of carbon, of 19 g C m^{-2}. This would suggest that the peat is degrading, and such that the losses from decomposition are greater than the gains from annual photosynthesis.

We emphasise that these results are provisional, and that all data will be re-processed offline. Also, the gap-filling procedure here is imperfect because of missing weather data. Substitute data for this has not yet been released by the ECN, so for some periods, a flux of zero is assumed. Furthermore, data coverage was particularly poor during the first four months of 2005, because of a run of instrument failures and lack of site access because of snow. Given a further year's data, together with the measurements of the other components of the carbon balance, a much improved estimate of the annual carbon balance will be available in the near future.

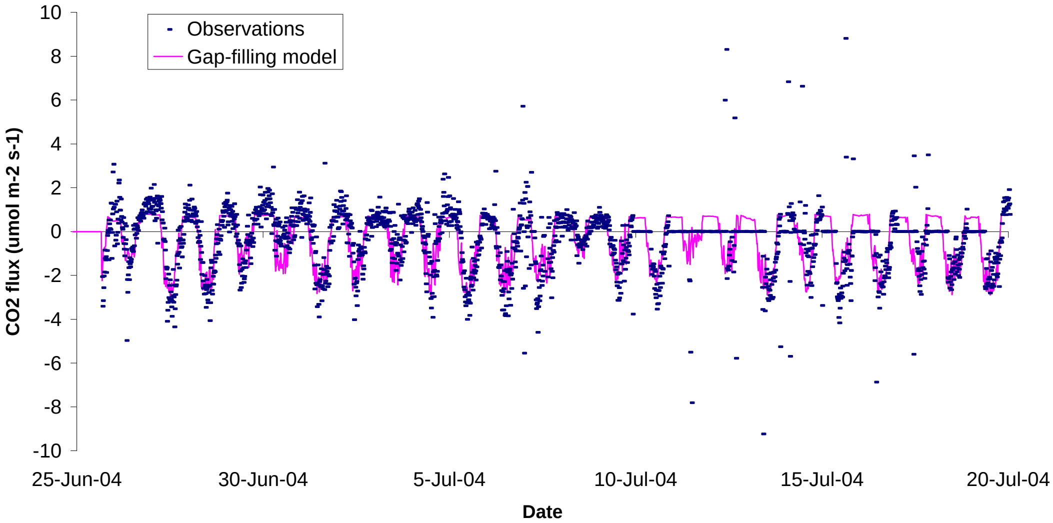

Figure 11-5 Comparison of observed CO_2 flux with gap-filling model estimates for the period 25 June to 20 July 2004.

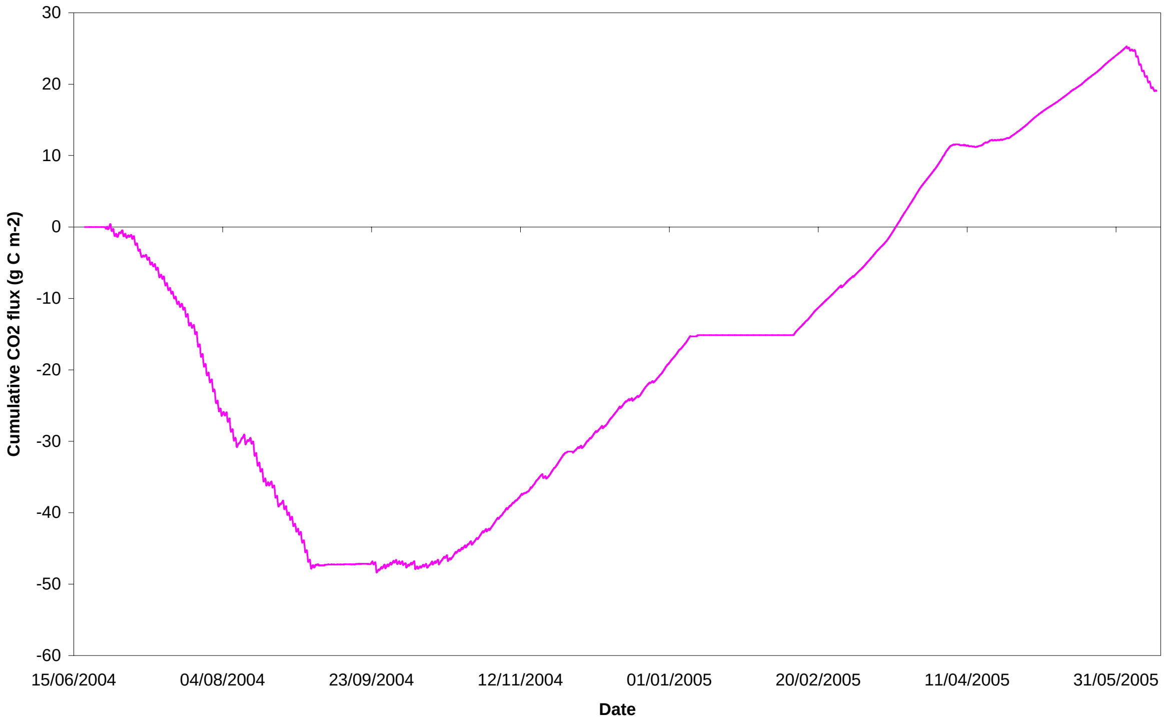

Figure 11-6 Cumulative CO_2 flux over the period 18 June 2004 to 13 June 2005, based on the eddy covariance measurements, with gap filling where necessary.

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11.5. Acknowledgements

We acknowledge the co-operation and assistance provided by English Nature and the CEH Environmental Change network.