Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry

Annual Report, July 2009

DEFRA Contract GA01088
CEH No. C03116

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EXECUTIVE SUMMARY

The overall aim of the project is to produce inventories and projections of UK greenhouse gas emissions by sources and removals by sinks due to Land Use, Land Use Change and Forestry (LULUCF) for three years from June 2006.

There are five specific objectives, addressed in six work packages.

1. To report an annual inventory and projections of greenhouse gas emissions by sources and removals by sinks associated with LULUCF to the EUMM and UNFCCC.

This objective is to fulfil the UK's national and international obligations to produce national inventories of emissions by sources and removal by sinks of greenhouse gases at a range of spatial scales (the UK, the individual countries within the UK, and the UK's Overseas Territories and Crown Dependencies). It also covers the additional reporting requirements under the Kyoto Protocol. As part of this objective, a publicly accessible, electronic archive of the LULUCF inventory and projections is produced.

Progress June 2008 - May 2009 (WP1.1-1.4 & WP6)
The 1990-2007 GHGI estimates for the LULUCF sector (and supporting text for the National Inventory Report) were completed and passed to the main inventory contractor (AEA) for submission to the European Union Monitoring Mechanism and the UN Framework Convention on Climate Change (UNFCCC) in March 2009.

There was estimated to be a net emission of 2929 Gg CO_2 (and 26 Gg CO_2e from non-CO_2 gases) from the LULUCF sector in the UK in 1990, but this flux had changed to a net removal of -1815 Gg CO_2 by 2007 (with 34 Gg CO_2e of emissions from non-CO_2 gases). Differences from the estimates in the previous inventory are due to improved methods for determining harvested wood products and other minor data revisions.

Estimates of LULUCF net emissions from the UK's Overseas Territories and Crown Dependencies were estimated from last years data due to lack of available of up to date data, these were estimated to be -28.8 Gg CO_2 in 1990 and -41.2 Gg CO_2 in 2007. For the separate countries in the UK, England is a net emitter between 1990 and 2007 (although on a downwards trend), while all other countries are net removers: Scotland has the largest, Northern Ireland and Wales are much smaller.

We have also produced Common Reporting Format tables of Kyoto Protocol activities (Art. 3.3 Afforestation, Reforestation and Deforestation and Art. 3.4 Forest Management) for voluntary submission to the UNFCCC and supplementary information on these tables. A new method for reporting Kyoto Protocol Article 3.3 afforestation estimates at more detailed spatial scales (20x20km rather than national) has been developed, which shows the pattern of carbon fluxes across the UK

CEH maintains a publicly accessible electronic archive of data and calculations relating to the LULUCF sector of the UK Greenhouse Gas Inventory on the website http://www.edinburgh.ceh.ac.uk/ukcarbon/. This archive will be updated with the latest inventory estimates for 1990-2007.

2. To ensure the integrity of the UK's inventory of greenhouse gas emissions by sources and removals by sinks relating to LULUCF, so that it is scientifically defensible, transparent, uses the full range of available relevant information and meets international reporting requirements.

The purpose of this objective is to ensure that the LULUCF inventory and projections are based on 'good science'. CEH and the other project partners work to enlarge and refine the datasets used to produce the inventory, verify inventory estimates through comparison with new data or methods, and undertake scientific research that does not have immediate applications in the inventory but increases our knowledge of the processes affecting fluxes of greenhouse gases within the LULUCF sector. This knowledge will stand the UK in good stead when responding to potential changes in the international reporting requirements in the future, for example, in 2012 after the end of the first Kyoto Protocol commitment period.

The work package (WP2) that addresses this objective is split into 16 sub-packages. Apart from WP 2.1, which is concerned with improved operational methods, these fall into five investigative groups. The first group is concerned with improvement of the inventory and projections through the assimilation of new data (WP 2.2 and 2.16). The second group is concerned with the analysis of information in existing datasets in more detail in order to improve the inventory (WP 2.3, 2.12 and 2.13). The third group is concerned with verification of existing components of the inventory through the collection and comparison of new field data (WP 2.4, 2.5 and 2.6) or through 'total carbon accounting' approaches (WP 2.14 and 2.15). The fourth group looks at potential gaps in the inventory, particularly the impact of changes in land use management (as opposed to land use change) on soil carbon stocks (WP 2.7 and 2.8). The last group is concerned with the long term aim of using ecological process-based models to estimate soil and vegetation carbon stock changes in the inventory rather than the present system of linked empirically-based models (WP 2.9, 2.10 and 2.11).

The science undertaken in these work packages underpins the inventory and links with all the other objectives. It contributes to the improvement and refinement of the inventory (Objective 1), provides necessary information for the quantification of uncertainties in Objective 3, links with other research initiatives in the individual countries in the UK and abroad (Objective 4) and is the foundation for the advice and promotion of scientific knowledge of LULUCF issues for Objective 5.

Progress June 2008 - May 2009 (WP2)

WP2.1 Improved operational methods for inventory calculations

Streamlining of the inventory production system has continued and there has been increased use of Matlab scripts to process and compile inventory data. The Matlab version of C-Flow was also used to produce the 5A inventory numbers. We have continued to add information to the web-based 'wiki' inventory manual, which is intended for CEH internal use only at this stage. The wiki is proving to be a useful resource, containing documentation and workflow procedures (the technical details of inventory methods) and with new information immediately available to all colleagues. The most significant recent development has been a successful bid for internal CEH funding (Science Budget) for 'Greenhouse gas inventory database development' starting in June 2008.

WP2.2 Incorporation of N2O and CH4 emissions and removals due to LULUCF

Emissions of greenhouse gases other than CO_2 in the Land Use Change and Forestry Sector (in the latest CRF tables) come from 4 types of activities: (i) application of fertilisers to forests producing N_2O, (ii) emissions from drainage of soils and wetlands, (iii) N_2O emissions from disturbance with land use conversion to cropland, and (iv) biomass burning.

Emissions from N fertilisation of newly planted forests have now been included in the inventory. There has been no progress in the estimation of emissions from drainage or land use conversion to cropland. This will be kept under review as more scientific information becomes available. The latest guidance/methodologies on the Agriculture, Forestry and Other Land Use sector in the IPCC 2006 Guidelines will also be examined and applied as appropriate. Emissions from biomass burning (from deforestation and wildfires) are reported in the inventory and described in Chapter 1; emissions from wildfires are included for the first time this year.

WP2.3 Methodology for incorporating effects of variability in forest characteristics

The Forest Land category (5A) is the largest net sink in the UK's LULUCF sector and flux estimates under Articles 3.3 and 3.4 of the Kyoto Protocol are also derived from this category. The LULUCF GHG inventory and projections for forest carbon stocks currently make a range of broad assumptions relating to species composition, productivity and forest management. The aim of this work package is to investigate these assumptions in more detail.

Forest Research extracted, processed and analysed data from the FC national inventory (NIWT I) carried out during the 1990s. This information was used to investigate spatial variation in the species composition and age class structure of woodlands across Great Britain. Data were summarised for grid squares with a resolution of 20 km x 20 km (the finest possible based on NIWT I) and the results were used to underpin the estimation of forest carbon stocks at this spatial scale. However, neither draft nor final versions of scenarios of forest management in the Devolved Administrations were fully prepared and reported, and the approach for representing the diversity of management across the UK forest estate remains unresolved.

The 2008 annual report discusses the original objectives/milestones with the view that they were too ambitious in the time available. The focus was adjusted to improve datasets and models for estimating carbon stock changes for Article 3.3 and 3.4 of the Kyoto Protocol.

WP2.4 Verification of C stocks in forest biomass using forest inventory data

During the contract period, there was an explosion of interest in methods for the management and assessment of forest carbon stocks and stock changes, all relevant to milestone II. Stakeholders in the forestry and biomass sectors, as well as wider commercial and environmental interest groups, made numerous requests for technical advice and support and it has been necessary to respond to this, including the adaptation of the national inventory assessment protocols to accommodate local monitoring initiatives.

As a consequence, significant progress has been achieved in the further development of a methodology for a British forest inventory that could form the essential basis of a forest carbon monitoring, verifying and reporting framework for England, Scotland and Wales. The approach has been designed to enable countries and smaller regions to adopt enhanced sampling to derive compatible estimates of carbon stocks and stock changes for specified localities with greater precision than would be offered by the basic inventory, as required. It has also been possible to develop related approaches that could be applied to monitoring of forest carbon at smaller scales, for example covering a few trees in a small woodland or a discrete forest estate of a few thousand hectares. In addition, an approach involving application of forest carbon accounting models has been characterised, with applications primarily to the design and evaluation of carbon management projects prior to implementation. In total, five approaches have been identified: (1) Model-based evaluation; (2) Full survey; (3) Plot-based survey; (4) Two-stage survey; and (5) Sample-based inventory. With the exception of model-based evaluation, the definitions of the methodologies concentrate on describing the estimation of carbon in standing trees, however it is envisaged that carbon in debris, litter and soil could be estimated through natural extensions of the methods.

WP2.5 Quantifying the effect of afforestation on soil carbon

This work package proposes to measure the effect of planting broadleaved trees on ex-agricultural mineral soils, using measurements at a number of sites where chronosequences are available. A site near CEH Edinburgh was used, where agricultural land had been planted with trees around 1980. This provided stands of different species (mainly Sitka spruce & birch) with known planting dates, as well as an unplanted control area, and a comparison with the rest of the field which had remained in agricultural use since 1980.

Although this is only one experiment at a single location the results imply that planting trees does not sequester as much carbon as we estimate in the LULUCF inventory. Currently, in the C-FLOW model, one third of the carbon is sequestered resides in the soil. These data are at odds with this, and suggest the soil may actually be a loss term. The results may not be generally applicable, but demonstrate the need for more data. The originally proposed work (see 2008 annual report), on monitoring carbon stocks at the SFA sites is particularly important in the light of these results, as there are very few experimental data available, and these provide a ready-made baseline.

WP2.6 Assessment of carbon fluxes in ploughed upland grassland

The objective of this work is to quantify the loss of carbon from semi-natural grassland soil following cultivation, by comparing cultivated and uncultivated treatments. Previous reports have described the set up of the experiment, pre-treatment measurements of soil carbon and soil respiration, and measurements of CO_2, N_2O and CH_4 fluxes.

The results showed that, contrary to expectation, loss of carbon was greater in the control plots. This we attribute to significant drying in the cultivated plots, which slowed down microbial decomposition. Strongly correlated with these differences in soil moisture, the control plots showed significantly higher N_2O emissions than the cultivated treatment. CH_4 uptake was significantly reduced by cultivation. To quantify the impact of cultivation on the net greenhouse gas balance, we combined the loss of soil carbon, CH_4 and N_2O fluxes, multiplied by their global warming potentials. The net effect of cultivation was to reduce global warming potential, mainly due to the reduction in CO_2 emission.

The applicability of this experiment to real agricultural land use changes is open to question, and there are likely to be important differences when a crop canopy is maintained on the soil surface. The implication of these results is that cultivation does not directly accelerate the decomposition of soil organic matter, and may actually impede it. This does not impinge on the procedure used in the LULUCF inventory, which is purely empirical, but does have implications for mitigation policies based on changes to tillage practice.

WP2.7 Assessment of land-use change on peatland carbon budgets

In recent years, there have been widespread attempts in the UK to restore peatlands to a more natural state, primarily by reversing drainage practices through the blocking of drains, and by deforesting conifer plantations. The objective of this work is to measure the effect of these changes in land management, primarily the blocking of drains, on the carbon balance of peatlands. A three-way comparative experiment has been set up, with sites that are pristine, drained, and drain-blocked, at the RSPB reserve at Forsinard, Sutherland. The experimental design has the advantage that all sites experience the same climate over the course of the experiment, and the comparison with a pristine site gives an appropriate baseline. A disadvantage is that we ascribe differences to a treatment effect when there could be inherent differences between sites. This problem is minimised by choosing sites as close together and as comparable as possible in all other respects. The sites chosen at Forsinard are very well-suited in this respect, all being within a few kilometres and otherwise similar. The eddy covariance system was set up at the pristine site in April 2008 and will run continuously thereafter, to give the background flux for the undisturbed state. Provisional analysis of the first year's flux data indicates that the site is a net sink of close to 100 g C m- y^{-1}. Flumes for monitoring catchment discharge were installed at three sites in Feb-March 2008, and fortnightly water sampling was begun in May 2008. Twelve flux chambers will be installed at each of the three sites in Autumn 2009, for regular measurements of CO_2 CH_4 and N_2O, when the man-power to run them will be available through a NERC PhD studentship. The results indicate that intact peat bogs are still acting as a sink for CO_2. The effect of drainage and restoration on this natural sink remains to be seen.

WP2.8 Statistical analysis of NSI soil carbon changes in relation to climate and land management changes

The National Soil Inventory (NSI) of England and Wales consists of 5662 sites that were sampled for soil in 1980, 40% of which were resampled between 1995 and 2003. Only a broad land use class was identified at the time of sampling. The objectives of this work package were to identify NSI sites and soil type-ecosystem combinations where the effects of changes in land management on soil carbon can be quantitatively distinguished from the effects of climatic changes. These sites could then be used to develop quantitative relationships between the changes in soil carbon and climate, land management, soil and other variables.

The number of sites identified with land management information was small. This severely limited the second objective of this project. From the analysis of the NSI data using a simple model of soil carbon turnover it is clear that climate change cannot be solely responsible for the large losses of organic carbon from the soils of England and Wales reported by Bellamy et al. (2005). It was found that neither changes in rates of decomposition resulting from the effects of climate change on soil temperature and moisture, nor changes in carbon input from vegetation, could by themselves account for the overall trends (Kirk and Bellamy in review). It was also concluded that past changes (i.e. before the first sampling) in land use and management were probably dominant.

This project has shown that there is a lack of detailed soil management information across all land uses in England and Wales and this has meant that the objectives of this project have only been met in part.

From the limited range of management scenarios investigated it is apparent that changes in management and variations of management within the broad land use categories assigned to the NSI sites have contributed to the loss of carbon. It has not been possible to identify explicit factors directly leading to a loss in soil carbon but indications from the data in this project and recently published literature suggest that the factors which contribute the most to soil carbon loss are historic land use change and land management, possibly explaining about 70-80% of the loss. We have shown that the effect of planting trees on bare land has an effect on soil carbon for over twenty years – far longer than has been reported previously.

It is clear that the effect of land use change and changes in land management can have long lasting effects on carbon in the soil. Any policy decision taken to try to stop the loss of carbon or to attempt to sequester carbon in the soil will need to be maintained over decades to be effective.

WP2.9 & 2.10 Testing a coupled soil and vegetation carbon process model/ Developing an above-ground component for the ECOSSE model

The inventory currently uses simplified methods to calculate changes in soil and plant carbon in response to land use change. A long term aim has been to use process based models instead. The main purpose of this work package was to develop models for plant and soil carbon and evaluate their potential usefulness in carbon reporting. This has resulted in a new model, RothC-Biota as well as coupling a soil carbon model to the UK land surface model, JULES.

The ECOSSE model has been applied in Scotland and Wales using inventory data on soils and land use change to drive the model, sowing proof of concept for use in AFOLU inventories. There is good agreement between ECOSSE and current inventory methods in estimates of changes in soil carbon due to land use change.

Models can now be used using inventory data. Preliminary results from application of the ECOSSE model in Scotland and Wales suggest a good agreement between ECOSSE predictions of soil C change due to land use change and those estimated by current inventory methods. The application of process-based in the AFOLU inventory is very close.

WP2.11 Approaches to incorporate the effects of climate change and land use change in LULUCF projections

The primary objective is to analyse the influence of changes in climate on the fluxes of carbon arising from land use change. A second objective is to separate the effects of changes in climate, CO_2 concentration and land use on the UK carbon balance.

To do this, we used a mechanistic model which represents the processes affected by climate and CO_2, and performed factorial simulations with and without changes in climate, CO_2, and land use. We can thereby extract the magnitude of the main effects and their interactions using classical ANOVA. The land use and land use change data were derived from the CEH Countryside Survey. Historical and projected climate data were obtained from CRU TS 1.2 and the SRES B2 scenario. These data were interpolated on to a 20 km grid covering GB. In the results for the period 1990 to 2020 climate change had the largest effect, reducing soil carbon by -0.6 kg C m^{-2}. Land use change also had a negative effect, at ~-0.3 kg C m^{-2}. CO_2 increased soil carbon by 0.1 kg C m^{-2}, and the interaction terms were small in all cases, so the net effect was close to the sum of these main effects. The simulations could be extended using alternative land use change matrices (from Forestry Commission planting data and ATEAM project projections) and a wider range of climate models and scenarios.

WP2.12 Inventory projections of harvested wood products

A position paper in the form of a science report was prepared (milestone VIII). This reviews the state of the art regarding national and international reporting of HWP carbon stocks, sinks and sources. At policy level, negotiations on a preferred method of HWP carbon reporting and accounting are still unresolved and as many as four different approaches are still under active consideration. The science report considers the implications of these four methods for estimation and reporting of HWP carbon in the UK context. Emphasis is placed on a model-based approach, with the details depending on which approach to reporting/accounting is ultimately adopted. While reporting approaches remain unagreed, it is too early to proceed with full implementation of any specific method and preparation of estimates (milestone XI). However, the science report describes the relevant modelling approaches. There have been no specific requests for estimates for particular HWP carbon accounting methodologies, but issues and implications of the different accounting methods have been discussed as part of presentations a contract progress meetings.

WP2.13 Development of Bayesian models of future land use change

This Work package aims to develop a method of estimating annual changes between different land uses in the Devolved Authorities of the UK starting from published data on how much land is in each use each year and a preliminary probability matrix of all possible transitions. Probability of change matrices would allow estimation of present and future change in stocks of carbon in soils etc.

Work so far has developed Bayesian statistics in Excel worksheets to calibrate change matrices for English land use in Arable, Grassland, Woodland, Developed and Other between 1990 and 2005. The approach developed was used to find annual matrices of change for both fixed transition probabilities and annually changing probabilities.

The matrices with annual changing probabilities suggested that changes of area from Grassland to Arable land are influenced by economic drivers. In order to describe such relationships more clearly it was recognised that the Grassland category should be split into managed (i.e. on farms) and unmanaged grassland.

Artificial test data for six land uses was developed to provide a more detailed test of the approach. The Bayesian calibration of a time varying land use change model was successful but illustrated that an adequate prior range for the parameters was required to allow the calibration to track the known parameter variation. Although the generated annual land areas did actually appear good for restricted prior parameter ranges.

It was concluded that the use of the Bayesian approach to estimating time-varying land use changes matrices from annual land use area data was a partial success. The approach can provided acceptable results when compared with known test data. The difficulty arises when there is no prior information about the variation with time of land use change probabilities. Such prior information may be available in the form of policy or financial data that would be correlated with changing LUC probabilities. Further research into the relationships between land use change probabilities and policy or financial drivers is recommended.

WP2.14 Verification approaches

The objective of WP2.14 is to organise three annual workshops on comparison of various possible approaches to the quantification of stocks and fluxes associated with land use change. This requires drawing together of the UK research community and linking with the recent initiatives arising from CarboEurope-IP. The researchers include (i) modellers, mostly within CTCD (ii) the eddy covariance flux community (iii) inventory specialists (iv) remote sensing specialists within CTCD and (v) atmospheric scientists operating with tall towers and aircraft.

Two workshops were held in Edinburgh (Jan 2008, March 2009), and a further workshop meeting was held as part of the National Centre for Earth Observation Agenda for Science meeting in May 2009. The first two engaged with the flux-measuring community; the final meeting discussed the ways in which Earth Observation may assist in evaluating UK and European carbon budgets, with emphasis on discussion about the usefulness of satellite data, particularly from GOSAT (Japan Aerospace Exploration Agency).

The meetings brought together most of the UK community interested in applying atmospheric measurements to infer the greenhouse gas sources and sinks. Those organisations who have been represented at the meetings are the Universities of Edinburgh, East Anglia, Leeds, Bristol, Royal Holloway College, CEH, Forest Research, the Meteorological Office and DEFRA (DECC). The first meeting discussed the state of art in greenhouse gas measurement in the UK, and the need to engage fully in the European project ICOS (Integrated Carbon Observing System). As a follow up to the meeting, representations were made to RCUK and as a result ICOS was inserted on the final version of the RCUK Large Facilities Roadmap, July 2008; its funding is now under discussion. We also identified stakeholders and have since endeavoured to stay in contact with them. The second meeting discussed specific technical issues, particularly the separation of biological and anthropogenic fluxes by means of 14C. Preliminary discussion on the design of a UK measuring system was initiated, and this was refined in subsequent e-mails and attendance at an ICOS meeting in Paris in May 2009.

WP2.15 Design of greenhouse gas observing systems

The aim of the work package was to estimate the magnitude of the biological carbon fluxes by using atmospheric data, and to see how far these fluxes are influenced by climatological variables; also to investigate how to disaggregate the fluxes into biological and anthropogenic origins. The land surface over which measurements can be done was not the whole of the UK, but just northern Britain, corresponding roughly to Scotland. This is because of the limited availability of tall tower observations. CO_2, CH_4 and N_2O has been measured; so far only CO_2 has been fully analysed. Concentrations of the gases were measured at tall tower Angus, in Fife, Scotland, and simultaneous data were obtained from Mace Head on the West of Scotland. Using a simple box model, it was possible to infer the net flux of GHG associated with passage of air from Ireland to the East of Scotland. In the summer months the landscape changes from being a source to being a sink for CO_2, implying that the biological fluxes are dominant over the anthropogenic fluxes. The magnitude of this pattern was so great as to imply that the biological sink, over the year, is of similar magnitude to the anthropogenic source. Error analysis has highlighted the need for (i) improved knowledge of the height of the planetary boundary layer (ii) use of trajectory analysis as an improved method. The result is very sensitive to any calibration differences between mace Head and tall tower Angus, although this appears to be well-controlled by the procedures in place at the two stations. To measure the GHG fluxes by the method of total carbon accounting with reference to the atmosphere is technically possible. It provides ‘total carbon accounting’ which cannot yield the same result as the national inventory because the latter ignores most of the biological fluxes, including only those which are obviously brought about by human activities.

WP2.16 Soil carbon and peat extraction in Northern Ireland

The aim of this year's work was to assess the importance of depth on C-stocks in upland (blanket) peat in Northern Ireland (NI). Earlier work on lowland (raised) bogs showed that the vast majority of lowland (basin) peats in NI had an organic carbon content of 51-52 %C, an average bulk density of 0.063 t/m^3 (0.052 t/m^3 for pristine peat) with no general increase observed down the peat profile for either bulk density or %C.

The C loss due to mechanized extraction of peat for domestic fuel was estimated for 1990-91 (Cruickshank et al., 1996) based on field survey across Northern Ireland. Subsequently, the extent of this extraction declined and a re-survey was required. A sampling approach was adopted whereby 5% of grid squares with lowland peatland and with blanket peatland were field checked for incidences (and their size) in 2007-08. Using the same rates of extraction (t peat/ha/yr) as in 1990-91 and the same % dry matter and %C, results from the sample were extended to Northern Ireland. *2. Hand fuel peat extraction.* Two blocks of NI were field checked in 2008 and the results expanded to NI. *3. Extraction for Horticulture.* Official data on this extraction was less available in 2007-08 than in 1990-91 so that the estimated C loss in 1990-91 had to be revised using methods that could be applied in 2007-08. For the most common form of extraction (vacuum), volume of peat extracted was calculated from area of a site and the depth of peat removed annually. The amount of C/litre was held constant from the 1990-91 results since vacuum methods had not changed. The estimates of carbon loss from peat extraction in 2008 range from 42 751 tC/yr to 47 452 tC/yr at low and high rates of peat extraction, or approximately 40% and 30% respectively of estimated losses in 1990-91 (Table 1). Whereas in 1990-91, peat extraction for fuel (hand and mechanical) accounted for 76-81% of carbon loss from peat extraction, in 2008 it accounted for 16-24%.

There has been an overall decline in annual carbon loss resulting from peat extraction during the period 1990-91 to 2007-8, caused mainly by a marked fall in extraction for fuel. The estimated error in area of machine fuel extraction resulting from the sampling strategy used for the 2007- 8 resurvey was quite large (329 ha ± 140 ha with 68% probability). The results show an increased carbon loss resulting from extraction of peat for horticulture between 1990-91 and 2007-08 of around 6000 tC/yr. However, carbon losses calculated are for a particular year and a number of factors could affect that estimated loss.

WP 2.17 Using the Tellus Survey's Gamma-Ray dataset to delineate the extent and depth of peat in Northern Ireland

The aim of this year's work was to assess the potential of the Tellus high resolution, natural radioactivity (gamma (φ) ray) dataset, acquired during a low-level airborne geophysical survey of Northern Ireland during 2005-06, for defining the extent and depth of peat across Northern Ireland. The contoured Tellus φ–ray dataset (in total counts per second, cps) was superimposed on the AFBI peatland classification map (derived from the AFBI soil map) in a GIS and the extent of peat compared to the φ-ray contour value. Peat extent (shallow as well as deep (>50 cm) peat) was found to correspond, more or less, to the 1200 cps contour across the Province. Using the area enclosed by the 1200 cps contour, the extent of peat in Northern Ireland was estimated to be approximately 1,550 km^2. This compares to the mapped peat extent, based on the AFBI soil survey, of 1,927 km^2.

The degree of absorption of φ–rays by peat was also examined. Two study areas (peat bogs in the NE and NW of Northern Ireland) were used to see if there was a consistent relationship between peat depth and φ–ray count rates from the Tellus dataset from which peat depth could be estimated. The studies showed that the relationship between peat depth and φ–ray count rates depended very much on the underlying geology i.e. the method needs to be calibrated for each major geological type. Moreover, there was some indication that the method may not be applicable for peat deeper than ~2m as the count rates appeared to vary little for peat over 2m deep.

3. To quantify uncertainties at the source or sink category level and for the inventory as a whole, and endeavour to reduce them where practically possible.

The fulfilment of this objective will allow us to provide much more complete and rigorous information on uncertainties in the UK National Inventory Report than has previously been possible. Once the uncertainty analysis is completed it will provide a focus for the improvement of the inventory in the future, by concentrating on those components that make the largest contribution to overall uncertainty.

Progress June 2007 - May 2008 (WP3)

WP3 has addressed the following scientific objective: “To quantify uncertainties at the source or sink category level and for the inventory as a whole, and endeavour to reduce them where practically possible.” WP3 has largely, but not completely, met this scientific objective. The WP has quantified uncertainties associated with the main component of LULUCF, i.e. forest afforestation plus productivity (5A, 5G). Uncertainty quantification for the other land-use changes was carried out in WP2.13 with technical support from WP3. However, the uncertainty quantification carried out for 5A+5G must still be seen as preliminary. First, the uncertainty of the calculated forest sink associated with assumptions about forest management was not assessed, due to lack of information about current forest management in the UK. Also, a lack of internally consistent information about the spatial heterogeneity of UK soils, and the response of their carbon pools to environmental change, precluded a complete assessment of the quality of the calculations carried out to produce the inventory.

The WP has used Monte Carlo methods for uncertainty quantification, both as a stand-alone approach and as part of a Bayesian calibration approach aimed at reducing uncertainties. The Bayesian methods were successful for other LUC than afforestation (see WP2.13), but for afforestation required more calibration data than were available. Therefore, the uncertainty quantification for 5A and 5G was restricted to Monte Carlo sampling to quantify the forward propagation of uncertainty of inputs and parameters, used by the CFLOW carbon-accounting model to calculate the carbon fluxes associated with afforestation and HWP.

The key results from the uncertainty quantification in WP3, besides those already reported in previous annual reports, were:

The uncertainty for the total carbon flux from 5A and 5G combined is much less than the sum of the two uncertainties viewed separately. This is because the opposite effect that harvesting has on both fluxes creates a negative correlation between the two. It is therefore not useful to only report uncertainties at the component level.

The carbon sink associated with afforestation is highly sensitive to the presence and parameterisation of the following two processes in the most recent version of CFLOW: (1) emission of C from decomposing organic matter that was already present in the soil at the time of afforestation, (2) the removal of carbon by grasses and shrubs in the period after planting before the forest canopy closes. Because uncertainty about these processes propagates strongly to the output, they need to be quantified more widely to establish whether they are spatially variable.

Furthermore, replacing the zero-order method (only dependent on time elapsed since planting) by which CFLOW calculates emission from pre-existing carbon by first-order methods (dependent on current pool sizes) changes the time-pattern of emissions significantly.

The sensitivity of calculated carbon fluxes to CFLOW parameters (both expansion factors and decomposition rates) is very large, but this is mainly for the flux sizes themselves and less so for how the fluxes change between years. The sensitivity to parameterisation thus has only a minor effect on the difference between fluxes in any given year and a reference year.

The uncertainty assessment has identified processes (the dynamics of pre-existing carbon and the role of undergrowth) whose magnitude needs to be examined more thoroughly. Otherwise the CFLOW model seems to be quite robust with respect to its input values and parameterisation, with the caveat that the consequences of changes in forest management have not been accounted for. Finally, the strong impact of the structural changes of CFLOW with respect to soil carbon dynamics suggests that a thorough comparison with other models would be worthwhile.

4. To participate in the UK national inventory system and collaborate, where necessary, with related research activities and with the contractors responsible for emissions from the agriculture sector and the total UK inventory.

The LULUCF inventory is not a stand-alone project but a component of the UK national inventory and the UK's Climate Change Programme. This objective aims to maintain the representation of LULUCF inventory issues at the national policy level and contribute to the fulfilment of the UK's obligations under the Kyoto Protocol through participation in the National System.

Progress June 2008 - May 2009 (WP4)

CEH has participated in the UK national system meetings as technical experts for LULUCF. We work closely with AEAT, the contractor responsible for the total UK inventory.

Project partners have taken part in a number of research collaborations relevant to the inventory during the 2008/09 project year. These include national collaborations, e.g. the ECOSSE project (SEERAD/WAG), LULUCF mapping at the local authority scale for AEA, forestry collaborations, participation in the Scottish Soil Strategy, participation of the NI Peatlands & Upland biodiversity Delivery Group, investigation of greenhouse gas emission mitigation options for the regional governments. International collaborations include NitroEurope IP, CarboEurope IP, IMECC, COST639 on “Greenhouse gas budget of soils under changing climate and land use”, CLIMSOIL and Carbo-Extreme an EU Framework VII project.

5. To build upon and promote scientific knowledge of LULUCF issues to provide technical advice to Defra, Devolved Administrations and partner organisations when needed.

Objective 5 is closely linked with Objective 4, with both concerned with the transfer of knowledge between the inventory and scientific experts and the wider policy and research community. Engagement with this wider community is essential so that the work done for the inventory can be integrated into the broader policy/research areas of climate change and terrestrial biogeochemical cycles.

Progress June 2008 - May 2009 (WP5)

This work package covers the provision of advice to the UK Government and Devolved Administrations on matters relating to the UK inventory and LULUCF activities and the development and promotion of scientific knowledge of LULUCF issues through meeting attendance and publications. Many meetings were attended and/or presented at, these ranged from regional to IPCC/international conferences, (details are given in 11a). There were a large number of requests for advice/information: 9 from DECC, 6 from devolved administrations/government agencies and 11 from universities/independent consultants. Seventeen publications arose from the inventory project and associated research, with a further 3 in press (details in 11a).

1. Annual inventory estimates for the UK (WP 1.1)

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1.1 Introduction

This section describes the 1990-2007 UK greenhouse gas inventory for the Land Use, Land Use Change and Forestry sector. The Land Use, Land Use Change and Forestry (LULUCF) sector differs from others in the Greenhouse Gas Inventory in that it contains both sources and sinks of carbon dioxide. The sinks, (or *removals* from the atmosphere), are presented as negative quantities. LULUCF is estimated to have been a net sink since 1999, amounting in 2007 to some –1.82 Mt CO_2 equivalent.

The estimates for LULUCF emissions and removals are from work carried out by the Centre for Ecology and Hydrology. The structure of this Section and of the main submission for the National Inventory Report and CRF Tables is based on the Categories of the Common Reporting Format tables agreed at the 9th Conference of Parties to the UNFCCC and contained in FCCC/SBSTA/2004/8 (see also IPCC 2003). The Sector 5 Report Tables in the CRF format for each year from 1990 to 2005 have been submitted using the CRF Reporter. The relationship of this reporting format to that used in pre-2004 NIRs from the UK is discussed in the 2004 National Inventory Report. The new AFOLU (Agriculture, Forestry and Other Land Use) format described in the IPCC 2006 Guidelines, which combines the Agriculture and LULUCF sectors into one, has not yet been adopted for greenhouse gas inventory reporting in Annex 1 countries.

Net emissions in 1990 are estimated here to be 2929 Gg CO_2 compared to 2928 Gg CO_2 in the 1990-2006 National Inventory Report. For 2006 a net removal of -1816 Gg CO_2 is estimated here compared to a net removal of -1953 Gg CO_2 in the 1990-2006 Inventory. These differences are due to improved methods for determining harvested wood products and other minor data revisions.

1.2 Methods

In the IPCC Good Practice Guidance (GPG) for Land Use, Land Use Change and Forestry (IPCC 2003), a uniform structure for reporting emissions and removals of greenhouse gases was described. This format for reporting can be seen as "land based": all land in the country is 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 the period since the last survey. 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) land 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 changes of carbon are reported in separate tables, *e.g*. greenhouse gases other than CO_2, but emissions from these activities are combined into the totals in a summary table for the Sector.

Following comments from the UN Expert Review Team in 2007 we have included annual land use transition matrices for the UK in 1990 and 2007 (Table 1-1 and Table 1-2). The initial areas in 1990 were estimated from the Countryside Survey data, translated into IPCC land use categories and adjusted to take account of other data sources. The Other Land category is used to take account of the discrepancy between the different data sources and the total land area of the UK. Land use change up to 2007 is calculated by rolling forward from the 1990 areas using land use change data from the Countryside Survey and data on forest planting and deforestation. The off-diagonal items (land use change data from the Countryside Survey, forest planting and deforestation datasets) in the matrix are used to estimate the fluxes in the LULUCF inventory: the diagonal items (land remaining in the same use, in italics) are included for information only.

Table 1-1: Land use transition matrix, ha, for the UK 1990-1991

From To	**Forest**	**Cropland**	**Grassland**	**Wet-lands**	**Settlements**	**Other Land**	**Total (final)**
Forest	*2 167 286*	1 633	18 748	-	759	-	2 188 427
Cropland	0	*5 380 616*	95 948	-	942	-	5 477 506
Grassland	212	83 447	*13 091 440*	-	4 663	-	13 179 762
Wetlands	-	-	-	-	-	-	-
Settlements	644	2 475	13 462	-	*1 937 096*	-	1 953 678
Other Land	-	-	-	-	-	*1 633 621*	1 633 621
Total (initial)	2 168 142	5 468 171	13 219 599		1 943 461	1 633 621	*24 432 994*

Table 1-2: Land use transition matrix, ha, for the UK 2005-2007

From To	**Forest**	**Cropland**	**Grassland**	**Wet-lands**	**Settlements**	**Other Land**	**Total (final)**
Forest	*2 426 780*	973	8 720	-	497	-	2 436 970
Cropland	0	*5 539 894*	95 948	-	942	-	5 636 785
Grassland	625	83 447	*12 512 822*	-	4 662	-	12 601 556
Wetlands	-	-	-	-	-	-	-
Settlements	445	2 475	13 462	-	*2 107 680*	-	2 124 062
Other Land	-	-	-	-	-	1633621	1 633 621
Total (initial)	2 427 849	5 616 789	12 630 952	-	2 113 782	1633621	*24 432 994*

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 the time when the change occurred is also encouraged.

Category 5A- Forest Land

All UK forests are classified as temperate and about 67% of these have been planted since 1921 on land that had not been forested for many decades. The Forest Land category is divided into *Category 5.A.1 Forest remaining Forest Land* and *Category 5.A.2 Land converted to Forest Land*. Category 5.A.1 is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland. Category 5.A.2 is 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) two time periods, 1920 – 1990 and 1991 onwards. Three activities are reported under 5.A.2: carbon stock changes on land converted to Forest Land, N_2O emissions from N fertilization of forests, and biomass burning emissions from wildfires on forest land.

Forest Land remaining Forest Land (5.A.1)

There are about 811,000 ha of woodland in the UK that were established prior to 1921 and therefore fall into category 5.A.1. It is apparent from the comparison of historical forest censuses that some of this forest area is still actively managed (see

Thomson in Milne *et al*. 2006), but overall this category is assumed to be in carbon balance because of its age, and hence there is zero carbon stock change.

The carbon stock changes (in living biomass, dead organic matter and soils) are entered as ‘Not Occurring’ (NO) in the Common Reporting Format tables. The possible contribution of this category to carbon emissions and removals will be considered in more detail in future reporting in association with the work carried out under work package 2.3.

Land converted to Forest Land (5.A.2)

The estimates of changes in carbon stock in the biomass and soils of the forests established since 1920 are based on activity data in the form of the area of forest planted annually, as published by the UK Forestry Commission and the Northern Ireland Department of Agriculture. Activity data are obtained annually from the same national forestry sources, which helps ensure time series consistency of estimated removals. The estimates of emissions and removals due to afforestation were updated with national planting statistics for 2007. The Forestry Commission/Forest Service also provide spatially disaggregated planting statistics: the methodology for including these data in the main inventory is still under development, as described in Chapter 2.

Methodology: Carbon stock changes

The carbon uptake by the forests planted since 1920 is calculated by a carbon accounting model, C-FLOW (Dewar & Cannell 1992, Cannell & 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 in products. Restocking is assumed in all forests. The method is Tier 3, as defined in the GPG LULUCF (IPCC 2003). Two types of input data and two parameter sets are required for the model (Cannell & 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 are 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.

As input data we use the combined area of new private and state planting from 1921 to 2007 for England, Scotland, Wales and Northern Ireland sub-divided into conifers and broadleaves. Restocking is dealt with in the model through the second and subsequent rotations, which occur after clearfelling at the time of Maximum Area Increment (MAI). Therefore areas restocked in each year do not need to be considered separately. The key assumption is that the forests are harvested according to standard management tables. However, a comparison of forest census data over time has indicated that there are variations in the felling/replanting date during the 20th century, i.e. non-standard management. These variations in management have been incorporated into the forest model, and the methodology will be kept under review in future reporting.

The C-FLOW model uses Forestry Commission Yield Tables (Edwards & Christie 1981) to describe forest growth after thinning commences and an expo-linear curve for growth before first 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 regime. Sitka spruce is the most common species in UK forests, being about 50% by area of all conifer forest. Milne *et al.* (1998) have shown that mean Yield Class for Sitka spruce varied across Great Britain from 10-16 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. It has therefore been assumed that all conifers in Great Britain follow the growth pattern of Yield Class 12 m^3 ha^{-1} a^{-1}, but in Northern Ireland Yield Class 14 m^3 ha^{-1} a^{-1} is used. Milne *et al.* (1998) also showed that different assumptions for broadleaf species had little effect on carbon uptake. It is assumed that broadleaf forests have the characteristics of beech (*Fagus sylvatica* L.) of Yield Class 6 m^3 ha^{-1} a^{-1}. The most recent inventory of British woodlands (Forestry Commission 2002) shows that beech occupies about 8% of broadleaf forest area (all ages) and no single species occupies greater than 25%. Beech was selected to represent all broadleaves as it has characteristics intermediate between fast growing species e.g. birch, and very slow growing species e.g. oak. However, using oak or birch Yield Class data instead of beech data has been shown to have an effect of less than 10% on the overall removal of carbon to UK forests (Milne *et al.* 1998). The use of beech as the representative species will be kept under review.

Irrespective of species assumptions, the variation in removals from 1990 to the present is determined by the afforestation rate in earlier decades and the effect this has on the age structure in the present forest estate, and hence on the average growth rate. At the current (declining) rate of forest expansion removals of atmospheric carbon increased until 2004 and have now started to decrease, reflecting the reduction in afforestation rate after the 1970s. This afforestation is all on ground that has not been under forest cover for many decades. Table 1-3 shows the afforestation rate since 1921 and a revised estimate of the present age structure of these forests.

Historical forest census data and the historical annual planting rates were compared in the 2006 project report. Forest censuses were taken in 1924, 1947, 1965, 1980 and the late 1990s. The comparison showed that discrepancies in annual planting rates and the inferred planting/establishment date (from woodland age in the forest census) are due to restocking of older (pre-1920) woodland areas and variations in the harvesting rotations. However, there is also evidence of shortened conifer rotations in some decades and transfer of woodland between broadleaved categories (e.g. between coppice and high forest). As a result, the afforestation series for conifers in England and Wales were sub-divided into the standard 59 year rotation (1921-2005), a 49 year rotation (1921-1950) and a 39 year rotation (1931-1940, England only). It is difficult to incorporate non-standard management in older conifer and broadleaved forests into the Inventory because it is not known whether these forests are on their first rotation or subsequent rotations (which would affect carbon stock changes, particularly in soils). Further work is planned for this area.

Table 1-3: Afforestation rate and age distribution of conifers and broadleaves in the United Kingdom since 1921.

Period	Planting rate (100 ha a^{-1})			Age distribution	
	Conifers on all soil types	**Conifers on organic soil**	**Broadleaves**	**Conifers**	**Broadleaves**
1921-1930	5.43	0.54	2.44	1.4%	7.8%
1931-1940	7.46	0.73	2.13	2.5%	8.4%
1941-1950	7.43	0.82	2.22	6.1%	11.8%
1951-1960	21.66	3.06	3.09	16.0%	11.4%
1961-1970	30.08	5.28	2.55	22.8%	8.3%
1971-1980	31.38	7.61	1.14	22.4%	5.9%
1981-1990	22.31	6.05	2.19	19.1%	4.9%
1991	13.46	3.41	6.71	0.9%	0.6%
1992	11.56	2.97	6.48	0.8%	0.6%
1993	10.06	2.43	8.87	0.7%	0.8%
1994	7.39	1.74	11.16	0.5%	1.0%
1995	9.44	2.37	10.47	0.6%	1.0%
1996	7.42	1.79	8.93	0.5%	0.8%
1997	7.72	1.87	9.46	0.5%	0.9%
1998	6.98	1.62	9.67	0.5%	0.9%
1999	6.63	1.44	10.12	0.5%	0.9%
2000	6.53	1.37	10.91	0.4%	1.0%
2001	4.90	1.01	13.45	0.3%	1.2%
2002	3.89	0.75	9.99	0.3%	0.9%
2003	3.74	0.72	9.22	0.3%	0.8%
2004	2.94	0.59	8.89	0.2%	0.8%
2005	2.10	0.40	9.19	0.1%	0.8%
2006	1.14	0.21	7.03	0.1%	0.6%
2007	2.15	0.39	8.05	0.1%	0.7%

Afforestation rates and ages of GB forests planted later than 1989 are from planting records. The age distribution for GB forests planted before 1990 is from the National Inventory of Woodland and Trees carried out between 1995 and 1999. The age distribution for pre-1990 Northern Ireland forests is estimated from planting records. Conifer planting on organic soil is a subset of total conifer planting. All broadleaf planting is assumed to be on non-organic soil.

The input data for increases in stemwood volume are based on standard Yield Tables, as in Dewar & Cannell (1992) and Cannell & Dewar (1995). These Tables do not provide information for years prior to first thinning so a curve was developed to bridge the gap (Hargreaves *et al.* 2003). The pattern fitted to the stemwood volume between planting and first thinning from the Yield Tables follows a smooth curve from planting to first thinning. The formulation 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 the stemwood volume by multiplying by species-specific wood density, stem:branch and stem:root mass ratios and the fraction of carbon in wood (0.5 assumed). The values used for these parameters for conifers and broadleaves are given in Table 1-4, together with the parameters controlling the transfer of carbon into the litter pools and its subsequent decay. The litter transfer rate from foliage and fine roots is assumed to increase over time to a maximum at canopy closure. A fixed fraction of the litter is assumed to decay each year, half of which is added to the soil organic matter pool, which then decays at a slower rate. Tree species and Yield Class are assumed to control the decay of litter and soil organic matter. Additional litter is generated at times of thinning and felling. These carbon transfer parameters have been used to split the living biomass output from C-Flow between gains and losses, rather than net change as before.

Table 1-4: Main parameters for forest carbon flow model used to estimate carbon uptake by planting of forests of Sitka spruce (*Picea sitchensis* and beech (*Fagus sylvatica*) in the United Kingdom (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
Maximum carbon in foliage (t ha^{-1})	5.4	6.3	1.8
Maximum 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
Maximum foliage litterfall (t ha^{-1} a^{-1})	1.1	1.3	2
Maximum 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

The estimates of carbon losses from afforested soils are based on measurements taken at deep peat moorland locations where afforestation occurred 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 tC ha^{-1} a^{-1} thirty years after afforestation. In addition, a short burst of regrowth of moorland plant species occurs before forest canopy closure.

Carbon incorporated into the soil under all new forests is considered in the inventory, 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 that same depth of deep peat. A simplified approach is taken to deciding on the proportionality factors, and it is assumed 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 assumed to proceed at half the rate of those in 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. The temporary re-growth of ground vegetation before forest canopy closure is, however, assumed to occur for all planting at the same rate as for afforested peat moorland. This assumption agrees with qualitative field observations at plantings on agricultural land in England.

It is assumed in the C-FLOW model that harvested material from thinning and felling is made into wood products. The net change in the carbon in this pool of wood products is reported in Category 5G.

Activity data are obtained consistently from the same national forestry sources, which helps ensure time series consistency of estimated removals.

Estimates of carbon stocks in above-ground living biomass, dead material and soils from work undertaken by the Forestry Commission should become available from 2009, which will allow the verification of carbon stock estimates from the C-Flow model.

Methodology: N2O emissions from forest fertilisation

Emissions of nitrous oxide from direct nitrogen fertilisation of forests are included in the inventory. Information on forest fertilisation was gathered from a search of the relevant literature and discussion with private chartered foresters and the Forestry Commission (Skiba 2007). In the UK the general recommendation is not to apply fertiliser to forests unless it is absolutely necessary: it is not applied to native woodlands, mature forest stands or replanted forests. The instances where N fertiliser is applied to forests are first rotation (afforestation) forests on ‘poor’ soil, e.g. reclaimed slag heaps, impoverished brown field sites, upland organic soils. In terms of the inventory, this means that N fertilisation is assumed for Settlement converted to Forest land and Grassland converted to Forest Land on organic soils. A Tier 1 approach is used with the amount of N fertiliser calculated using a fixed application rate and the areas of relevant forest planting taken from the same dataset used in the CFlow model for 5.A.2. Land converted to Forest land.

An application rate of 150 kg N ha^{-1} is assumed based on Forestry Commission fertilisation guidelines (Taylor 1991). The guidelines recommend applying fertiliser on a three-year cycle until canopy closure (at c. 10 years), but this is thought to be rather high (Skiba 2007) and unlikely to occur in reality, so two applications are adopted as a compromise. These applications occur in year 1 and year 4 after planting. As a result, emissions from N fertilisation since 1990 include emissions from forests that were planted before 1990 but received their second dose of fertiliser after 1990. The emission factor for N_2O of applied nitrogen fertiliser is the default value of 1.25%. Emissions of N_2O from N fertilisation of forests have fallen since 1990 due to reduced rates of new forest planting.

Methodology: Emissions from wildfires on forest land

Estimates of emissions from wildfires on forest land are included in the inventory for the first time this year. These fires only affect a small area in the UK and do not result in land use conversion. The approach is Tier 2, using country-specific activity data and default emission factors. There is no information as to the age and type of forest that is burnt in wildfires, so all wildfire emissions are recorded under 5.A.2, which includes all land converted to forest since 1921.

Estimates of the area burnt in wildfires 1990-2007 (Table 1-5) are published in different locations (FAO/ECE 2002; Forestry Commission 2004; FAO 2005) but all originate from either the Forestry Commission (Great Britain) or the Forest Service (Northern Ireland). No data on areas burnt in wildfires has been collected or published since 2004, although this is apparently under review. Activity data for 2005 to 2007 is extrapolated using a Burg regression equation based on the trend and variability of the 1990-2004 dataset. These areas refer only to fire damage in state forests (); no information is collected on fire damage in privately owned forests.

Table 1-5: Area burnt in wildfires in state (Forestry Commission) forests 1990-2007 (* indicates an estimated area)

Year	Area burnt, ha			
	Great Britain	Northern Ireland	UK	% UK forest area burnt
1990	185	127	312	0.021%
1991	376*	88*	464	0.042%
1992	92*	22*	114	0.010%
1993	157*	37*	194	0.018%
1994	123*	24	147	0.014%
1995	1023*	16	1039	0.119%
1996	466	94	560	0.055%
1997	585	135	720	0.069%
1998	310	22	332	0.037%
1999	45	9	54	0.005%
2000	165	6	171	0.020%
2001	181	85	266	0.023%
2002	141	85	226	0.018%
2003	147	1	148	0.019%
2004	146	91	237	0.019%
2005	5*	75*	80*	0.008%
2006	429*	3*	432*	0.045%
2007	412*	97*	508*	0.054%

The area of private-owned forest that was burnt each year was assumed to be in proportion to the percentage of the state forest that was burnt each year. An estimated 921 ha of forest was burnt on average every year (the sum of state-owned and privately-owned forests) between 1990 and 2007.

There is no information on the type (conifer or broadleaf) or age of forest that is burnt in wildfires in the UK. Therefore, the amount of biomass burnt is estimated from the mean forest biomass density in each country of the UK, as estimated by the C-Flow model. These densities vary with time due to the different afforestation histories in each country (Table 1-6).

Table 1-6: Biomass densities, tonnes DM ha^{-1}, used to estimate mass of available fuel for wildfires

Year	Forest biomass density, tonnes DM ha^{-1}				
	England	Scotland	Wales	Northern Ireland	UK
1990	92.372	59.531	84.793	88.159	71.394
1995	97.184	69.535	95.832	97.727	80.189
2000	100.937	79.323	101.856	106.353	88.056
2005	107.628	93.177	119.397	116.110	100.353
2007	110.301	98.319	125.671	118.154	104.846

A combustion efficiency of 0.5 is used with a carbon fraction of dry matter of 0.5 to estimate the total amount of carbon released, and hence emissions of CO_2 and non-CO_2 gases (using the IPCC emission ratios).

Data reporting in the Common Reporting Format Tables (IPCC 2003)

The data for carbon stock changes in living biomass, dead organic matter and soils from afforestation are entered in Sectoral Background Table 5.A in section 2 Land converted to Forest Land. The data are disaggregated into changes resulting from the afforestation of Cropland, Grassland and Settlements and reported by (a) the four geographical areas of England, Scotland, Wales and Northern Ireland, and (b) two time periods, up to 1990 and 1991 onwards.

The latest version of the CRF tables requires the area of organic soil to be reported with the total area and net carbon stock changes to be split between mineral and organic soils. All broadleaf planting is assumed to be on mineral soil and conifer planting is split between mineral and organic soils (based on country-specific activity data). There is assumed to be no conversion of Cropland to Forest Land on organic soils in England, Wales or Northern Ireland and no conversion of Settlement to Forest Land in Northern Ireland (reported as NO - Not Occurring). The C-Flow model has been adapted to report net soil carbon stock changes split between the two different soil types, as well as living biomass stock changes split between Gains and Losses (instead of Net changes as previously).

The removals due to carbon stock changes in harvested wood products calculated here are entered into Sectoral Report Table 5, as “G Other, Harvested Wood Products”.

N_2O emissions from N fertilization of Forest Land are reported in Table 5(I). The data reported are the total amounts of fertilizer applied and the resulting emissions. N fertilizer is only applied to newly planted Forest Land so these emissions are reported under A.2. Land converted to Forest Land.

Emissions from wildfires on Forest Land are reported in Table 5(V) Biomass Burning. The amount of biomass burnt and the resulting emissions are reported. There is no information on the type or age of forest where wildfires have occurred so all wildfires are reported under Land converted to Forest Land, as this category contains the majority of UK forests reported in the inventory. Emissions from wildfires on Forest Land remaining Forest Land are recorded as Included Elsewhere (notation key IE).

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. A Matlab version of C-FLOW that runs with grid input data is now complete. Spatially disaggregated data sets for forest planting back to 1990 are now complete (see work package 2.3 for further details). This approach is being developed to meet the requirements of the Kyoto Protocol for more geographically explicit data for reporting removals due to afforestation and deforestation under Article 3.3. An investigation of the impact of forest management (species planting mix, thinning, harvest age) on forest carbon stocks and fluxes is also underway, enabled by access to more detailed forest datasets. This will contribute to the reporting of removals due to forest management under Article 3.4.

Work is also planned to investigate further the effect of afforestation on soil carbon, specifically the effect of planting broadleaved trees on ex-agricultural mineral soils. This research will get underway in the summer of 2008, and the results of this research will be included in the inventory in due course.

Cropland (5B)

The category is disaggregated into *5.B.1 Cropland remaining Cropland* and *5.B.2 Land converted to Cropland*. Category 5.B.1 is further disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland.

Three activities are considered for 5.B.1: the effect on non-forest biomass due to crop yield improvements, the effect of fenland drainage on soil carbon stocks (which occurs only in England) and carbon dioxide emissions from soils due to agricultural lime application to Cropland (which is also disaggregated into application of Limestone ($CaCO_3$) and Dolomite ($CaMg(CO_3)_2$)). Category 5.B.2 is disaggregated into conversions from Forest Land, Grassland and Settlements. These conversions are further disaggregated by a) the four geographical areas of England, Scotland, Wales and Northern Ireland, and b) two time periods, 1950 – 1990 and 1991 onwards.

N_2O emissions from disturbance associated with land use conversion to Cropland are not reported (Skiba *et al.* 2005). This assessment was discussed in last year's report (see Chapter 6).

Cropland remaining Cropland (5.B.1)

Methodology - Changes in non-forest biomass resulting from yield improvements

This is the annual increase in the biomass of cropland vegetation in the UK that is due to yield improvements (from improved species strains or management, rather than fertilization or nitrogen deposition). Under category 5.B.1 an annual value is reported for changes in carbon stock, on the assumption that the annual average standing biomass of cereals has increased linearly with increase in yield between 1980 and 2000 (Sylvester-Bradley *et al.* 2002).

Data are reported as a constant average value in each year.

Methodology – Application of Lime

Emissions of carbon dioxide from the application of limestone, chalk and dolomite to cropland were estimated using the method described in the IPCC 1996 Guidelines (IPCC, 1997a, b, c). Data on the use of limestone, chalk and dolomite for agricultural purposes is reported in the Business Monitor of Mineral Extraction in the UK (Office of National Statistics 2007). Estimates of the individual materials are provided by the British Geological Survey each year as only the totals are published because of commercial confidentiality rules for small quantities. It is assumed that all the carbon within the applied material is released in the year of use.

The method for estimating CO_2 emissions due to the application of lime and related compounds is that described in the IPCC 1996 Guidelines. For limestone and chalk, an emission factor of 120 tC/kt applied is used, and for dolomite application, 130 tC/kt. These factors are based on the stoichiometry of the reaction and assume pure limestone/chalk and dolomite. CO_2 emissions, weight for weight, from limestone and chalk are identical since they have the same chemical formula. Dolomite, however, has a slightly higher emission due to the presence of magnesium.

Dolomite may be calcinated for use in steel making; however, some of this material is not suitable and is returned for addition to agricultural dolomite – this fraction is reported in ONS (2007) as 'material for calcination' under agricultural end use. Calcinated dolomite, having already had its CO_2 removed, will not cause emissions of CO_2 and therefore is not included here. Lime (calcinated limestone) is also used for carbonation in the refining of sugar but this is not specifically dealt with in the UK LULUCF GHG Inventory.

Lime is applied to both grassland and cropland. The annual percentages of arable and grassland areas receiving lime in Great Britain for 1994-2006 were obtained from the Fertiliser Statistics Report (Agricultural Industries Confederation 2006) and the British Survey of Fertiliser Practice (BSFP 2007). The 2006 figures have been repeated in the 2007 inventory as this data was not available in time for the 2007 inventory, due to the time restrains future liming applications will be based on the previous years data. Percentages for 1990-1993 were assumed to be equal to those for 1994.

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.

Methodology – Lowland drainage

Lowland wetlands in England were drained many years ago for agricultural purposes and continue to emit carbon from the soil, i.e. there is an ongoing change in soil carbon stock. 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 1 m deep) and the rest with thinner peat. Different loss rates were assumed for these two thicknesses (Table 1-7). The large difference between the implied emission factors is due to the observation that those peats described as 'thick' lose volume (thickness) more rapidly that those peats described as 'thin'. The 'thick' peats are deeper than 1m, have 21% carbon by mass and in general have different texture and less humose topsoil than the 'thin' peats, which have depths up to 1m (many areas ~0.45 m deep) and carbon content of 12% by mass.

Table 1-7: Area and carbon loss rates of UK fen wetland in 1990

	Area	**Organic carbon content**	**Bulk density** kg m^{-3}	**Volume loss rate** $m^3 m^{-2} a^{-1}$	**Carbon mass loss** GgC a^{-1}	**Implied emission factor** gC $m^{-2} a^{-1}$
'Thick' peat	$24x10^7$ m^2 (24,000 ha)	21%	480	0.0127	307	1280
'Thin' peat	$126x10^7$ m^2 (126,000ha)	12%	480	0.0019	138	109
Total	**$150x10^7$ m^2 (150 kha)**				**445**	**297**

The emissions trend since 1990 was estimated assuming that no more fenland has been drained since then and that existing drained areas have continued to lose carbon. The annual loss for a specific location decreases in proportion to the amount of carbon remaining. Furthermore, as the peat loses carbon it becomes more mineral in structure. The Century model of plant and soil carbon was used to average the carbon losses from these fenland soils over time (Bradley 1997): further data on how these soil structure changes proceed with time is provided in Burton (1995).

The emissions due to lowland drainage are obtained from a model driven by activity data from a single source, which provides good time series consistency.

Data Reporting

The net emissions due to increases in non-forest biomass are disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.B Cropland under carbon stock change in living biomass. The latest version of the CRF tables requires the area of organic soil to be reported with the total area: it is not possible to do this for this activity.

The emissions from agricultural lime application are entered into Sectoral Background Table 5 (IV) (CO_2 emissions from agricultural lime application). The data are disaggregated by application of limestone and dolomite separately on Cropland (and Grassland).

The emissions due to lowland drainage are entered into Sectoral Background Table 5.B under net carbon stock change in soils. This applies only to England so there is no further disaggregation. The area of lowland drainage activity is all on organic soil.

Planned Improvements

These activities will be kept under review, with reference to input data and appropriateness of reporting category.

Land Converted to Cropland (5.B.2)

Methodology - Changes in non-forest biomass stocks resulting from land use change to Cropland

This is the annual change in the carbon stock in vegetation biomass due to all land use change to Cropland, excluding forests and woodland. Estimates of emissions and removals for this category are made using the Countryside Survey Land Use Change matrix approach, with biomass densities weighted by expert judgment.

Changes in carbon stocks in biomass due to land use change are based on the same area matrices used for estimating changes in carbon stocks in soils (see following section). The biomass carbon density for each land type (

Table 1-8) is assigned by expert judgement based on the work of Milne & Brown (1997). Five basic land uses were assigned initial biomass carbon densities, then the relative occurrence of these land uses in the four countries of the UK were used to calculate mean biomass carbon densities for each of the IPCC types, Cropland, Grassland and Settlements. Biomass carbon stock changes due to conversions to and from Forest Land are dealt with elsewhere. The mean biomass carbon densities for each land type were then weighted by the relative proportions of change occurring between land types (Table 1-9 to Table 1-12), in the same way as the calculations for changes in soil carbon densities. Changes between these equilibrium biomass carbon densities were assumed to happen in a single year. Data are reported as a constant average value in each year.

Table 1-8: Equilibrium biomass carbon density (kg m^{-2}) for different land types

Density (kg m-2)	Scotland	England	Wales	N. Ireland
Arable	0.15	0.15	0.15	0.15
Gardens	0.35	0.35	0.35	0.35
Natural	0.20	0.20	0.20	0.20
Pasture	0.10	0.10	0.10	0.10
Urban	0	0	0	0
	IPPC types weighted by occurrence			
Cropland	0.15	0.15	0.15	0.15
Grassland	0.18	0.12	0.13	0.12
Settlements	0.29	0.28	0.28	0.26

Table 1-9: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in England (Transitions to and from Forestland are considered elsewhere)

From To	**Forestland**	**Cropland**	**Grassland**	**Settlements**
Forestland				
Cropland		0	-0.08	-0.13
Grassland		0.08	0	-0.08
Settlements		0.13	0.08	0

Table 1-10: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in Scotland. (Transitions to and from Forestland are considered elsewhere)

From To	**Forestland**	**Cropland**	**Grassland**	**Settlements**
Forestland				
Cropland		0	-0.02	-0.14
Grassland		0.02	0	-0.09
Settlements		0.14	0.09	0

Table 1-11: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in Wales. (Transitions to and from Forestland are considered elsewhere)

From To	Forestland	Cropland	Grassland	Settlements
Forestland				
Cropland		0	-0.07	-0.13
Grassland		0.07	0	-0.08
Settlements		0.13	0.08	0

Table 1-12: Weighted average change in equilibrium biomass carbon density (kg m^{-2}) for changes between different land types in Northern Ireland. (Transitions to and from Forestland are considered elsewhere)

From To	Forestland	Cropland	Grassland	Settlements
Forestland				
Cropland		0	-0.08	-0.11
Grassland		0.08	0	-0.06
Settlements		0.11	0.06	0

Methodology – Changes in soil carbon stocks due to land use change to Cropland

Land use change results in soil carbon stock change, because soil carbon density generally differs under different land uses and the land use change initiates a transition from one density value to another. Under the methodology for this activity, all forms of land use change, including deforestation, are considered together and both mineral and organic soils are included.

The method for assessing changes in soil carbon stock due to land use change links a matrix of change from land surveys to a dynamic model of carbon stock change. For Great Britain (England, Scotland and Wales), matrices from the Monitoring Landscape Change (MLC) data from 1947 & 1980 (MLC 1986) and the ITE/CEH Countryside Surveys (CS) of 1984, 1990 and 1998 (Haines-Young *et al.* 2000) are used. In Northern Ireland, less data are available to build matrices of land use change, but for 1990 to 1998 a matrix for the whole of Northern Ireland was available from the Northern Ireland Countryside Survey (Cooper & McCann 2002). The only data available pre-1990 for Northern Ireland are land use areas from the Agricultural Census and the Forest Service (Cruickshank & Tomlinson 2000). Matrices of land use change were then estimated for 1970-80 and 1980-90 using area data. The basis of the method devised assumed that the relationship between the matrix of land use transitions for 1990-1998 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 to match the start year in the rest of the UK (Table 1-13).

Table 1-13: 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 Good Practice Guidance for Land Use, Land Use Change and Forestry (IPCC 2003) recommends use of six classes of land for descriptive purposes: 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 been placed into the five other types. The more detailed categories for the two surveys in Great Britain were combined as shown in Table 1-14 or MLC and Table 1-15 for CS.

The area data used between 1947 and 1998 in Great Britain are shown in

Table 1-16. 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 1-17- Table 1-20. 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 for Land converted to and from Forest Land.

Table 1-14: Grouping of MLC land cover types for soil carbon change modelling

CROPLAND	**GRASSLAND**	**FORESTLAND**	**SETTLEMENTS (URBAN)**	**OTHER LAND**
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 1-15: Grouping of Countryside Survey Broad Habitat types for soil carbon change modelling.

CROPLAND	**GRASSLAND**	**FORESTLAND**	**SETTLEMENTS (URBAN)**	**OTHER LAND**
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			

Table 1-16: 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 - 2006	*Extrapolated*	CS1990 → CS1998

Table 1-17: 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 1-18: 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 1-19: Annual changes (000 ha) in land use in Wales 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		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 1-20: Annual changes (000 ha) in land use in Northern Ireland in matrix form for 1990 to 1999. Based on land use change between 1990 and 1998 from Northern Ireland Countryside Surveys (Cooper & 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	

A database of soil carbon density for the UK (Milne & Brown 1997, Cruickshank *et al.* 1998, Bradley et al. 2005) is used in conjunction with the land use change matrices. There are three soil survey groups covering the UK and the field data, soil classifications and laboratory methods of each group were harmonized to reduce uncertainty in the final database. The depth of soil considered was also restricted to 1 m maximum as part of this process. The total stock of soil carbon (1990) and the soil carbon densities under different land types in the four devolved areas of the UK are shown in Table 1-21 and Table 1-22.

Table 1-21: Soil carbon stock (TgC = MtC) for depths to 1m under the IPCC land categories

Region / **Type**	England	Scotland	Wales	N. Ireland	**UK**
Forestland	108	295	45	20	467
Grassland	995	2,349	283	242	3,870
Cropland	583	114	8	33	738
Settlements	54	10	3	1	69
Other	0	0	0	0	-
TOTAL	**1,740**	**2,768**	**340**	**296**	**5,144**

Table 1-22: Soil carbon densities (kg m^{-2}) in the United Kingdom under the IPCC land categories

	Soil depth 0-30 cm						**Soil depth 30-100 cm**				
	Organic	**Organo-mineral**	**Mineral**	**Other**	**All**		**Organic**	**Organo-mineral**	**Mineral**	**Other**	**All**
England											
Forestland	22.9	12.2	10.7	3.5	9.2		90.5	8.0	4.3	2.2	6.8
Cropland	17.0	17.3	7.7	2.9	6.7		64.2	6.3	4.3	1.8	4.3
Grassland	19.9	11.7	9.6	3.4	8.3		52.3	7.2	5.0	2.3	6.5
Settlement	10.5	6.6	4.7	2.0	3.9		32.6	1.1	2.4	1.1	2.0
Scotland											
Forestland	22.3	23.7	25.1	4.7	22.6		50.0	11.8	9.0	3.3	20.2
Cropland	22.6	13.9	12.1	3.6	12.2		55.2	4.2	3.3	1.2	3.7
Grassland	22.3	22.7	18.8	3.6	20.2		51.2	8.7	5.8	2.6	18.4
Settlement	11.3	7.8	7.3	1.5	7.2		28.0	2.5	2.3	0.5	2.3
Wales											
Forestland	23.6	12.1	13.7	4.2	11.7		90.8	7.7	4.0	2.8	8.6
Cropland	20.6	9.3	7.5	3.1	6.6		74.5	6.5	4.7	1.8	4.2
Grassland	21.4	10.8	11.0	3.8	9.7		67.4	7.1	5.4	2.7	7.4
Settlement	10.5	5.3	4.6	2.3	4.1		30.4	3.8	2.2	1.3	2.2
Northern Ireland											
Forestland	13.3	20.1	19.6	0.0	17.2		31.0	7.5	13.9	0.0	19.4
Cropland	13.0	8.6	12.8	0.0	12.6		30.3	4.5	8.7	0.0	9.6
Grassland	13.2	20.8	16.1	0.0	16.1		30.8	7.9	11.5	0.0	14.3
Settlement	6.5	9.8	7.4	0.0	7.4		15.2	2.9	5.1	0.0	5.2

The dynamic model of carbon stock change requires the change in equilibrium carbon density from the initial to the final land use. The core equation describing changes in soil carbon with time for any land use transition is:

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

where

C_t is carbon density at time t

C_0 is carbon density of initial land use

C_f is carbon density after 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:

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

A Monte Carlo approach is used to vary the inputs for this equation: the rate of change (k), the area activity data (A_T) and the values for soil carbon equilibrium under initial and final land use (C_f-C_0) for all countries in the UK. The model was run 1000 times using inputs selected from within ranges described set by prior knowledge, e.g. literature, soil carbon database, agricultural census, LUC matrices. The mean carbon flux for each region resulting from this approach is reported as the estimate for the Inventory. An adjustment is made to these calculations for each country to remove increases in soil carbon due to afforestation, as a better value for this is found from the C-Flow model used for the Land converted to Forest Land category. 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 change in equilibrium carbon density from the initial to the final land use are calculated for each land use category as averages for Scotland, England, Northern Ireland and Wales. 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:

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

This is the weighted mean, for each country, of change in equilibrium soil carbon when land use changes, where:

i = initial land use (Forestland, Grassland, Cropland, Settlements)

j = new land use (Forestland, Grassland, Cropland, Settlements)

c = country (Scotland, England, N. Ireland & Wales)

s = soil group (organic, organo-mineral, mineral, unclassified)

C_{sijc} is change in equilibrium soil carbon for a specific land use transition, L_{sijc}.

The most recent land use data (1990 to 1998) is used in the weighting. The averages calculated are presented in Table 1-23 to Table 1-26.

Table 1-23: Weighted average change in equilibrium soil carbon density (t ha^{-1}) 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 1-24: Weighted average change in equilibrium soil carbon density (t ha^{-1}) to 1 m deep for changes between different land types in Scotland

From To	Forestland	Grassland	Cropland	Settlements
Forestland	0	47	158	246
Grassland	-52	0	88	189
Cropland	-165	-90	0	96
Settlements	-253	-187	-67	0

Table 1-25: Weighted average change in equilibrium soil carbon density (t ha^{-1}) 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 1-26: Weighted average change in equilibrium soil carbon density (t ha^{-1}) 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 1-27). 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. A literature search for information on measured rates of changes of soil carbon due to land use was carried out and ranges of possible times for completion of different transitions were selected, in combination with expert judgement (Table 1-28).

Table 1-27: Rates of change of soil carbon for land use change transitions. ("Fast" & "Slow" refer to 99% of change occurring in times shown in
Table 1-28)

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

Table 1-28: 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 2005 database values for each transition and the uncertainty indicated by this source (up to ± 11% of mean). The areas of land use change for each transition were assumed to fall a range of uncertainty of ± 30% of mean.

As regards data quality, land use change activity data are obtained from several sources. The sources for Great Britain have separate good internal consistency, but there is poorer consistency between sources and with the data for Northern Ireland. There may be carry-over effects on emission/removal estimates for the reported years due to the long time response of soil systems.

Data Reporting

The carbon stock change in living biomass due to the increase in non-forest biomass in this category is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.B.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.B. The data for deforestation is included at the UK level while conversion of Grassland and Settlements to Cropland is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and two time periods (pre and post 1990).

The latest version of the CRF tables requires the area of organic soil to be reported with the total area and net carbon stock changes to be split between mineral and organic soils. It is not currently possible to extract these split results from the model although this will be investigated; currently data in the organic soil columns is reported as Included Elsewhere.

The data reported for the UK in Sectoral Table 5 in the Information item "Grassland converted to other Land-Use Categories" are changes in carbon stock in soils after change to another land use category.

Planned Improvements

There has been work on improving the spatial and temporal scale of the land use change matrices in non-inventory projects, the results of which will be incorporated into the inventory in due course. As part of the ECOSSE project (funded by the Scottish Executive and Welsh Assembly), detailed regional LUC matrices were developed for Scotland and Wales for 1950-1980 (Smith *et al.* 2007). Similar work has now been completed for England. A comparison of the results from the national and detailed land use change matrices has taken place (Work Package 2.8), however the results have not been conclusive and more data is needed before the results can be feed back into the national inventory.

New versions of the GB and Northern Ireland Countryside Surveys were undertaken in 2007, the results have recently become available and are currently being customized for use in the 2008 inventory. The updating of these datasets will allow the extension of the land use change matrices from 1998 to 2007.

Experimental work to detect the effect of cultivation (i.e. Grassland converted to Cropland) on CO_2 and N_2O fluxes and on soil carbon stocks has taken place over this contract period (Work Package 2.6). The results showed that, contrary to expectation, loss of carbon was greater in the control plots. The applicability of this experiment to real agricultural land use changes is open to question, and there are likely to be important differences when a crop canopy is maintained on the soil surface. The implication of these results is that cultivation does not directly accelerate the decomposition of soil organic matter, and may actually impede it. This does not impinge on the procedure used in the LULUCF inventory, which is purely empirical, but does have implications for mitigation policies based on changes to tillage practice.

Grassland (5C)

The Category is disaggregated into *5.C.1 Grassland remaining Grassland* and *5.C.2 Land converted to Grassland*. Category 5.C.1 is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland. Two activities are considered for 5.C.1: the impact of peat extraction for horticultural use and carbon dioxide emissions from soil due to agricultural lime application to Grassland (which is also disaggregated into application of Limestone ($CaCO_3$) and Dolomite ($CaMg(CO_3)_2$)). Three activities are considered for 5.C.2: emissions from biomass burning after conversion of Forestland to Grassland, changes in non-forest biomass due to LUC to Grassland and changes in soil carbon stocks due to LUC to Grassland. Conversions from Cropland and Settlements to Grassland are further disaggregated by a) the four geographical areas of England, Scotland, Wales and Northern Ireland and b) two time periods, 1950 – 1990 and 1991 onwards. Biomass burning emissions due to conversion of Forest Land to Grassland is reported at the 5C level for all of the UK in two time periods, 1950-1990 and 1990 onwards.

Grassland remaining Grassland (5.C.1)
Methodology – Application of Lime

See Cropland section for methodological details on agricultural liming on Cropland and Grassland.

Methodology – Peat Extraction

Peat is extracted in the UK for use as either a fuel or in horticulture. Only peat extracted for use in horticulture is now reported in the LULUCF sector. Peat extracted for fuel use is reported in the Energy Sector of the UK Inventory.

Cruickshank & Tomlinson (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 2006 have been estimated from activity data taken from the Business Monitor of Mineral Extraction in Great Britain (Office of National Statistics 2007). In Northern Ireland, no new data on use of peat for horticultural use has been available but a recent survey of extraction for fuel use suggested that there is no significant trend for this purpose. The contribution of emissions due to peat extraction in Northern Ireland is therefore incorporated as constant from 1990 to 2006. Peat extraction is negligible in Wales. Emissions factors for this activity are from Cruickshank & Tomlinson (1997) and are shown in Table 1-29**.**

Table 1-29: Emission factors for peat extraction

	Emission Factor kg C m^{-3}
Great Britain Horticultural Peat	55.7
Northern Ireland Horticultural Peat	44.1

As the activity data for peat extraction come from a number of sources, only some of which are reliable, the time series consistency is medium.

Data Reporting

The emissions from agricultural lime application are entered into Sectoral Background Table 5 (IV) Carbon emissions from agricultural lime application. The data are disaggregated by application of limestone and dolomite separately on Grassland (and Cropland).

The emissions due to peat extraction are entered into Sectoral Background Table 5.C, disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland. The area of peat extraction is all on organic soil.

Planned Improvements

All emission factors and activity data will be kept under review. A repeat survey of peat extraction (for fuel and horticultural use) in Northern Ireland has taken place over this contract period (work package 2.16). The results show an increased carbon loss resulting from extraction of peat for horticulture between 1990-91 and 2007-08 of around 6000 tC/yr. However, carbon losses calculated are for a particular year and a number of factors could affect that estimated loss.

Land converted to Grassland

Methodology - Emissions from biomass burning after conversion of Forest Land to Grassland

Emissions of CO_2, CH_4 and N_2O result from the burning of forest biomass when Forest Land is converted to Grassland. The interpretation of the available data allows the emissions to be disaggregated into deforestation to Grassland and Settlements. Deforestation to Cropland in the UK is negligible.

Levy & Milne (2004) discuss methods for estimating deforestation using a number of data sources. Their approach of combining Forestry Commission felling licence data for rural areas with Ordnance Survey data for non-rural areas was adopted for the inventory.

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, around 14,000 ha a^{-1} was 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 areas deforested. 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.

The most recent deforestation rate available for rural areas is for 2002 so rates for 2003-2007 were estimated by extrapolating forwards from the rates for 1999 to 2002.

Only local planning authorities hold documentation for allowed felling for urban development, and the need for collation makes estimating the national total difficult. However, in England, the Ordnance Survey (national mapping agency) makes an annual assessment of land use change from the data it collects for map updating and provides this assessment to the Department of Communities and Local Government. Eleven broad land-use categories are defined, with a number of sub-categories. The data for England (1990 to 2007) are available 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 on non-rural deforestation.

The rural and non-rural 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 licensed 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 five-year moving average was applied to the data to smooth out the between-year variation appropriately, to give a suitable estimate with annual resolution. Deforestation is not currently estimated for Northern Ireland. Rural deforestation is assumed to convert the land to Grassland use (reported in Category 5C2) and non-rural deforestation causes conversion to the Settlement land type (reported in 5E2). Information from land use change matrices shows that conversion of forest to cropland is negligible.

Where deforestation occurs it is assumed that 60% of the standing biomass is removed as timber products and the remainder is burnt. The annual area loss rates were used in the method described in the IPCC 1996 guidelines (IPCC 1997c, 1997a, 1997b) to estimate immediate emissions of CO2, CH4 and N2O from this biomass burning. Only immediate losses are considered because sites are normally completely cleared for development, leaving no debris to decay. Changes in stocks of soil carbon after deforestation are included with those due to other land use transitions.

The time series consistency of emissions from this activity is only medium given that the two constituent data series are not both available for each year and the values for several years are partially derived from data in one region. Areas deforested in non-rural areas have been revised for each year from 1990 and updated to 2006. Data on rural deforestation is only available up to 2002; therefore areas for 2003-2007 were estimated by extrapolation from earlier years.

Methodology – Changes in Non forest biomass due to land use change to Grassland

This is the annual change in the carbon stock in biomass of vegetation due to all land use change, excluding forests and woodland, to Grassland. See Cropland section for details on non-forest biomass calculations.

Methodology – Changes in soil carbon stocks due to land use change to Grassland

This is the change in soil stocks due to land use change to Grassland. Details of the methodology are given in the Cropland section.

Data Reporting

Emissions of CO_2, CH_4 and N_2O from biomass burning after conversion of land to Grassland are included in Sectoral Background Table 5 (V) Biomass Burning.

The carbon stock change in living biomass due to the increase in non-forest biomass in this category is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.C.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.C. The data for deforestation is included at the UK level while conversion of grassland and settlements to Grassland is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland plus two time periods (pre- and post-1990).

The latest version of the CRF tables requires the area of organic soil to be reported with the total area and net carbon stock changes to be split between mineral and organic soils. It is not currently possible to extract these split results from the model although this will be investigated; currently data in the organic soil columns is reported as Included Elsewhere.

The data reported for the UK in Sectoral Table 5 in the Information item “Forest Land converted to other Land-Use Categories” includes both changes in carbon stock in biomass (due to burning) and soils under “Net CO_2 emissions/removals”.

Planned Improvements

All emission factors and activity data will be kept under review. Input data for the deforestation activity remain a problem and work to assimilate relevant data sources for each of the four UK countries is under discussion.

Wetlands (5D)

In the UK, Wetlands will either be saturated land (e.g. bogs, marshes), which will fall into the Grassland category due to the classifications used in the Countryside Survey, or open water (e.g. lakes, rivers, reservoirs), which is included in the Other Land category. Sectoral Background Table 5.D. Wetlands is therefore completed with ‘IE’ (Included Elsewhere).

Settlements (5E)

Category 5.E (Settlements) is disaggregated into 5.E.1 Settlements remaining Settlements and 5.E.2 Land converted to Settlements. The area of Settlements in Category 5.E.1 is considered not to have long term changes in carbon stock. Category 5.E.2 is disaggregated into conversions from Forest Land, Cropland and Grassland and these conversions are further disaggregated by a) the four geographical areas of England, Scotland, Wales and Northern Ireland and b) two time periods, 1950 – 1989 and 1990 onwards. Biomass burning emissions due to conversion of Forest Land to Settlements are reported at the 5E level for all of the UK from 1990 onwards (emissions occur in the same year as the land use conversion).

Settlements remaining Settlements (5.E.1)

No changes in carbon stocks are reported for land remaining under Settlements. 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

Data Reporting

Sectoral Background Table 5.E.1 Settlements remaining Settlements is completed with ‘NO’ (Not Occurring).

Planned Improvements

None are planned at the present time.

Land converted to Settlements

Methodology – Emissions from biomass burning after conversion of Forest Land to Settlements

Emissions of CO_2, CH_4 and N_2O result from the burning of forest biomass when Forest Land is converted to Settlements. The interpretation of the available data allows the emissions to be disaggregated into deforestation to Grassland and Settlements. Deforestation to Cropland is negligible. The methodology is described in the Grassland section.

Methodology - Changes in non-forest biomass due to land use change to Settlements

See the Cropland section for details on non-forest biomass calculations.

Methodology – Changes in soil carbon stocks due to land use change to Settlements

This is the change in soil stocks due to land use change to Grassland. Details of the methodology are given in the Cropland section.

Data Reporting

Emissions of CO_2, CH_4 and N_2O from biomass burning after conversion of land to Settlements are included in Sectoral Background Table 5 (V) Biomass Burning.

The carbon stock change in living biomass due to the increase in non-forest biomass in this category is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland and entered into Sectoral Background Table 5.E.2 Land Converted to Settlements. The area of land associated with each set of data is also included in Sectoral Background Table 5.E.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.E.2 Land converted to Settlements. The data for deforestation is included at the UK level while conversion of Grassland and Cropland to Settlements is disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland plus two time periods (pre- and post-1990).

The data reported for the UK in Sectoral Table 5 in the Information item “Forest Land converted to other Land-Use Categories” includes both changes in carbon stock in biomass (due to burning) and soils under “Net CO_2 emissions/removals”.

The data reported for the UK in Sectoral Table 5 in the Information item “Grassland converted to other Land-Use Categories” are changes in carbon stock in soils after change to another land use category.

Planned Improvements

All emission factors and activity data will be kept under review. Input data for the deforestation activity remain a problem and work to assimilate relevant data sources for each of the four UK countries is under discussion.

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 that become bare rock or water bodies, which make up the majority of this type. Therefore Sectoral Background Table 5.F Other Land is completed with 'NO' (Not Occurring).

Other Activities (5G)

Changes in stocks of carbon in harvested wood products (HWP) are reported here.

Methodology

The carbon accounting model (C-Flow) is used to calculate the net changes in carbon stocks of harvested wood products, in the same way as it is used to estimate carbon stock changes in 5.A. The C-Flow model method can be described as Tier 3, as defined in the GPG LULUCF (IPCC 2003). It calculates the amount of carbon in the different stock pools of new even-aged plantations (i.e. forest planted on land that previously under a non-forest land use) of conifers and broadleaves. These are assumed to be under an intermediate thinning management regime with clear-felling and replanting at the time of Maximum Area Increment (57 or 59 years for conifers and 92 years for broadleaves). Both thinnings and harvested materials are assumed to enter the HWP stock pool, where they decay at different rates. Only harvested wood products from UK forests planted since 1921 (i.e. those reported in 5.A.2) are included: the decay of imported products is not considered at present, pending international agreement on a single methodology to be used for reporting.

The C-Flow model adopts a simple approach to the decay of Harvested Wood Products (HWP). The activity data used for calculating this activity is the annual forest planting rates. For a given forest stand, carbon enters the HWP pool when thinning is undertaken (depending upon the species thinning first occurs c. 20 years after planting) and when harvesting takes place.

A living biomass carbon stock loss of 5% is assumed to occur immediately at harvest (this carbon is transferred to the litter or soil pools). The remaining 95% is transferred to the HWP pool. The residence times of wood products in the HWP pool depend on the type and origin of the products and are based on exponential decay constants. Residence times are estimated as the time taken for 95% of the carbon stock to be lost (from a quantity of HWP entering the HWP pool at the start).

Harvested wood products from thinnings are assumed to have a lifetime (residence time) of 5 years, which equates to a half-life of 0.9 years. Wood products from harvesting operations are assumed to have a residence time equal to the rotation length of the tree species. For conifers this equates to a half life of 14 years (59 years to 95% carbon loss) and for broadleaves a half life of 21 years (92 years to 95% carbon loss). This approach captures differences in wood product use: fast growing softwoods tend to be used for shorter lived products than slower growing hardwoods.

These residence time values fall mid range between those tabled in the LULUCF GPG (IPCC 2003) for paper and sawn products: limited data were available for the decay of HWP in the UK when the C-Flow model was originally developed. A criticism of the current approach is that the mix of wood products in the UK may be changing and this could affect the 'true' mean value of product lifetime. At present there is very limited accurate data on either decay rates or volume statistics for different products in the UK, although this is kept under review.

The C-Flow method does not precisely fit with any of the approaches to HWP accounting described in the IPCC Guidelines (2006) but is closest to the Production

Approach (see Thomson and Milne in Milne and Mobbs 2005). The UK method is a top-down approach that assumes that the decay of all conifer products and all broadleaf products can be approximated by separate single decay constants. While this produces results with high uncertainty it is arguably as fit-for-purpose as bottom-up approaches where each product is given an (uncertain) decay and combined with (uncertain) decay of other products using harvest statistics which are in themselves uncertain.

According to this method the total HWP pool from UK forests is presently increasing, driven by historical expansion of the forest area and the resulting history of production harvesting (and thinning). The stock of carbon in HWP (from UK forests planted since 1921) has been increasing since 1990 but this positive stock change rate recently reversed, reflecting a severe dip in new planting during the 1940s. The net carbon stock change in the HWP pool has returned to a positive value (i.e. an increasing sink) in 2003, and is forecast to decrease sharply.

Activity data are obtained consistently from the same national forestry sources, which helps ensure time series consistency of estimated removals.

Data Reporting

Removals of CO_2 associated with harvested wood products are included in Sectoral Report Table 5, as “G Other, Harvested Wood Products”.

Planned Improvements

The emission factors and activity data for harvested wood products will be kept under review. Work carried out during this contract period reviled that it was too early to proceed with full implementation of any specific method and preparation of estimates.

1.3 Results

Data for the 1990 to 2007 GHG Inventory are presented in Appendices 1 to 4 of this volume. The data for this period (2009 Inventory submission date) are summarised in Table 1-31.

The Appendices contain data in the following formats:

A.1. Summary Tables for 1990 to 2020 in LULUCF GPG Format

A.2. Sectoral Tables for Land Use Change and Forestry Sector submitted as UK 2006 Greenhouse Gas Inventory in LULUCF GPG format

A.3. Sectoral Tables for Land Use Change and Forestry Sector for the Devolved Administration Regions

A.4. Removals and Emissions by activities under Article 3.3 and 3.4 of the Kyoto Protocol.

The Sectoral and Background Tables (5, 5A, 5B, 5C, 5D, 5E, 5F, 5(I), 5(II), 5(III), 5(IV) and 5(V)) in the Common Reporting Format of the LULUCF GPG are presented in a companion Data Table volume on CD for each year 1990 to 2007. Summary data is also provided in the Data Table volume for the Devolved Administration areas of England, Scotland, Wales and Northern Ireland.

All data are reported in Gg (10^9 g) of CO_2 equivalent.

Forest Land (5A)

Forest Land Remaining Forest Land (5.A.1)

Changes in stocks of carbon in Forest Land in the UK that remains Forest Land are assumed to be zero. This category is identified with 811,000 ha of forest that has existed since before 1920 and is also assumed to be in carbon balance because of its age and therefore has zero stock change.

Land converted to Forest Land (5.A.2)

All afforestation (1,682,000 ha) occurring since 1920 is reported in this category. There were no change in the method this year but the estimates were updated with planting statistics for 2007. Net carbon stock changes resulting in atmospheric removals have varied over time: starting from -12,202 Gg in 1990 and reaching a maximum of -16,298 Gg in 2004. The net carbon stock change in 2007 was -14,340 Gg. These changes reflect variation in planting rates in past decades which feed through growth and harvesting to the carbon uptake trends reported here. CO_2 emissions and non-CO_2 emissions from wildfires are included in this sector. N fertilization of forests are also included in the inventory.

Cropland (5B)

Cropland Remaining Cropland (5.B.1)

Changes in carbon stocks resulting from changes in non-forest biomass from yield improvements, application of lime and lowland drainage are reported in this category. There were no changes in the methodology but due to the unavailability of data there have been no updates (ONS 2007 and BGS personal communication). Overall, the carbon stock changes in this category result in net emissions, which appear to be on a downward trend, starting from 1788 Gg in 1990 (with a peak of 1930 Gg in 1991) to 959 Gg in 2007. This trend is mainly driven by the declining emissions from lowland drainage, which has fallen steadily from 1650 Gg in 1990 to 1129 Gg in 2007. Removals from non-forest biomass yield improvements are constant, and emissions due to liming, although variable, do not show any consistent trend.

Land Converted to Cropland (5.B.2)

Carbon stock changes resulting from changes in non-forest biomass and soil carbon stocks due to land use change to Cropland are reported in this category. There were no recalculations done for this category.

Emissions from land converted to Cropland show a small but steady rate of increase, from 14,034 Gg in 1990 to 14,329 Gg in 2007. This trend is due to changes in soil carbon stocks as changes in non-forest biomass stocks occur at a fixed rate.

Grassland (5C)

Grassland Remaining Grassland (5.C.1)

Changes in carbon stocks due to application of lime to Grassland and peat extraction are reported in this category. Estimates of emissions were taken from the 2006 data (ONS 2007 and BGS personal communication), the 2007 data was not available to be included into this years inventory. All future reports will use the previous year's data, this situation will be monitored and if the data becomes available earlier changes will be made to include the most recent figures. Estimated emissions from Grassland have remained constant when comparing the 2006 data with the numbers for 2006 in the previous submission (2008 NIR).

Emissions from this category are variable over the time period, starting at 1,041 Gg in 1990, with a peak of 1,277 Gg in 1995, and then falling away to 564 Gg in 2002, with an emission of 701 Gg in 2007. Both of the carbon stock changes which contribute to this category are variable over time, but the downward trend between 1995 and 2002 seems to be mainly due to a reduction in emissions from liming of Grassland.

Land Converted to Grassland (5.C.2)

Changes in carbon stocks due to emissions from biomass burning after conversion of Forest Land to Grassland and changes in non-forest biomass and soil carbon stocks due to land use change to Grassland are reported in this category. The revision of the deforestation dataset resulted in a re-allocation of areas in the land use change matrix, producing changes in emission/removal estimates from those in the previous National Inventory Report. There was a change of 47 Gg CO2 in 2006 (compared with the estimate for 2006 in the 2008 NIR).

Overall, this category results in a net removal from the atmosphere, which has increased over time, from -7,205 Gg in 1990 to 8,767 Gg in 2007. This trend is entirely due to changes in soil carbon stocks from land converted to Grassland, as changes in non-forest biomass stocks are a small and constant removal (-198 Gg a-1), and changes due to biomass burning after deforestation are an equally small although variable emission (30-180 Gg a-1).

Settlements (5E)

Settlements Remaining Settlements (5.E.1)

No changes in carbon stocks are reported in this category.

Land Converted to Settlements (5.E.2)

Changes in carbon stocks due to emissions from biomass burning after conversion of Forest Land to Settlements and changes in non-forest biomass and soil carbon stocks due to land use change to Settlements are reported in this category. The data on the area of deforestation in non-rural areas was revised for the 2006 NIR, this is explained in last years report. There was a change of 110 Gg CO2 for 2006 compared with the 2006 estimate submitted in the 2008 NIR.

Overall, this category results in a net emission to the atmosphere, although this is slowly decreasing over time, from 6,972 Gg in 1990 to 6,259 Gg in 2007. This trend is due to changes in soil carbon stocks from land converted to Settlements, as removals due to biomass changes and emissions due to biomass burning after deforestation are both small.

Other Activities (5G)

Changes in carbon stocks in this category result from changes in harvested wood products. The estimates of emissions/removals were updated with planting statistics for 2007. This category produced a net removal from the atmosphere in 1990 of -1,682 Gg, decreasing to become a net emission of -793 Gg in 1994, then rising to -1,513 Gg in 1999, before a sharp decrease reaching a net emission 368 Gg in 2005. This activity has now become a net removal again in 2005 and has increased to -1293 Gg in 2007. This variability is driven by both forest planting and harvesting patterns in previous decades (see Thomson in the 2006 annual report) and a change in the way harvested wood products are reported.

Net UK Emissions/Removals

The picture of net emissions/removals from the Land Use Change and Forestry Sector in the UK has not changed significantly from the previous Inventory, as the data revisions that have been made are relatively minor. The net emission in 1990 is calculated to be 2,929 Gg rather than 2,928 Gg in the previous NIR. For 2006 a net removal of -1816 Gg CO_2 is estimated here compared to a net removal of -1953 Gg CO_2 in the 2006 Inventory. These differences are due to improved methods for determining harvested wood products and other minor data revisions.

England is a net emitter between 1990 and 2007 (although on a downwards trend), while Scotland (with removals increasing 1990-2005) and Northern Ireland (with removals increasing 1990-2006) are net removers. Wales has a small net removal but does not have the strong trend shown in the other countries. The net emissions for the UK follow a downward trend, reaching zero between 1998 and 1999 and flattening out in 2004 to -1771, this years (2007) a net removal is -1815 Gg.

1.4 LUCF GHG Data on basis of IPCC 1996 Guidelines

The structure of this report and the 2009 submissions of the National Inventory Report and the main submission of CRF Tables, are based on the Categories of the Common Reporting Format tables agreed at the 9th Conference of Parties to the UNFCCC and contained in FCCC/SBSTA/2004/8, also referred to as the IPCC 2003 Good Practice Guidelines CRF categories. Tables showing the relationship between the previous IPCC 1996 categories and the GPG categories can be found in the 2006 project report and the 1990-2004 National Inventory Report. The reported totals for emissions and removals for the LULUCF Sector are the same in either format.

1.5 Uncertainties

Approximate uncertainties for different activities used in the IPCC GPG reporting structure are shown in Table 1-30. An uncertainty of 20% was estimated for CH_4 and N_2O emissions from biomass burning after deforestation (categories 5C2 and 5E2). The uncertainty for the wildfire activity data is estimated to be 50% for the activity data 1990-2004, but 100% for the 2005 to 2007 values, as these have been extrapolated from previous years. The IPCC default of 70% uncertainty is used for the emission factors. A full analysis of uncertainties is planned for future versions of the Inventory.

Table 1-30: Approximate uncertainty of estimates of emissions/removals for LULUCF GPG categories

IPCC Source Category	**Uncertainty in 1990 CO_2 emissions/removals, %**	**Uncertainty in 2005 CO_2 emissions/removals, %**
5A Forest Land	25	25
5B Cropland	45	50
5C Grassland	70	55
5D Wetland	-	-
5E Settlements	35	50
5F Other Land	-	-
5G Other Activities	30	30

1.6 LULUCF reporting for the UK's Overseas Territories and Crown Dependencies

The UK should include direct GHG emissions in its GHGI from those UK Crown Dependencies (CDs) and Overseas Territories (OTs) which have joined, or are likely to join, the UK's instruments of ratification to the UNFCCC and the Kyoto Protocol. Currently, these are: Guernsey, Jersey, the Isle of Man, the Falkland Islands, the Cayman Islands, Bermuda, Montserrat and Gibraltar. An MSc project to calculate

LULUCF net emissions/removals for the OTs and CDs was undertaken during 2007 (Ruddock 2007).

The availability of data for the different OTs and CDs was very variable, so that emission estimates could only be made for the Isle of Man, Guernsey, Jersey and the Falkland Islands. These four comprise over 95% of the area in all the OTs and CDs. Gibraltar wished to produce their own inventory: their LULUCF net emissions/removals are likely to be extremely small, given the size of the country (6km^2), and will have little impact on overall numbers. A lack of suitable data for the Caribbean territories (discussed below) made it impossible to create inventories for them at the present time.

Information on the area of each IPCC land category, dominant management practices, land use change, soil types and climate types were compiled for each OT/CD from statistics and personal communications from their government departments and global land/soil cover databases. This allowed Tier 1 level inventories to be constructed for the four OT/CDs already mentioned, and a Tier 3 approach for Forest Land on the Isle of Man (using the C-Flow model also used for the UK).

The estimated net flux from the LULUCF sector in the UK's OTs and CDs was -28.8 Gg CO_2 in 1990 and -41.2 Gg CO_2 in 2006. The net flux was variable over time (with a peak of -91.9 Gg CO_2 in 1992), which largely seemed to be driven by the variability in the 5C2 (Land converted to Grassland) category in the Isle of Man. The estimates have high uncertainty and probably do not capture all relevant activities, in particular land use change to Settlement from land uses other than Forest Land (there are no default IPCC methods for these transitions).

Table 1-31: Emissions and removals in categories within 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	2004	2005	2006	2007
5	**NET**	**2929**	**2841**	**1950**	**1124**	**917**	**1242**	**1000**	**693**	**77**	**-202**	**-339**	**-460**	**-978**	**-1030**	**-1771**	**-1934**	**-1816**	**-1815**
5A	**Forest-Land**	**-12155**	**-12636**	**-13320**	**-13679**	**-14164**	**-13728**	**-13605**	**-13360**	**-13322**	**-13489**	**-13756**	**-14280**	**-14986**	**-15595**	**-16238**	**-15721**	**-15091**	**-14173**
5A1	*Forest-Land remaining Forest-*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5A2	*Land converted to Forest-Land*	*-12202*	*-12715*	*-13340*	*-13713*	*-14192*	*-13947*	*-13719*	*-12715*	*-13340*	*-13714*	*-14192*	*-13947*	*-13719*	*-13510*	*-13405*	*-13502*	*-13801*	*-14344*
5A2 (wildfires)	*Biomass burning in forest wildfires*	*47*	*79*	*20*	*35*	*28*	*219*	*114*	*150*	*83*	*13*	*46*	*63*	*54*	*45*	*60*	*13*	*146*	*166*
5B	**Cropland**	**15822**	**15978**	**15983**	**15566**	**15618**	**15750**	**15788**	**15530**	**15418**	**15321**	**15339**	**15287**	**15313**	**15384**	**15316**	**15233**	**15279**	**15288**
5B1	*Cropland remaining Cropland*	*1788*	*1930*	*1920*	*1487*	*1522*	*1637*	*1657*	*1381*	*1251*	*1136*	*1136*	*1065*	*1072*	*1126*	*1039*	*939*	*968*	*959*
5B2	*Land converted to Cropland*	*14034*	*14048*	*14063*	*14079*	*14096*	*14113*	*14131*	*14148*	*14166*	*14185*	*14203*	*14222*	*14240*	*14258*	*14276*	*14294*	*14312*	*14329*
5B (liming)	*Liming of Cropland*	*779*	*957*	*984*	*587*	*660*	*811*	*868*	*628*	*535*	*456*	*493*	*444*	*473*	*549*	*484*	*406*	*457*	*470*
5C	**Grassland**	**-6130**	**-6075**	**-6512**	**-6609**	**-6548**	**-6461**	**-6705**	**-6822**	**-7220**	**-7124**	**-7221**	**-7176**	**-7512**	**-7321**	**-7640**	**-7689**	**-7790**	**-7967**
5C1	*Grassland remaining Grassland*	*1041*	*1211*	*1215*	*926*	*1094*	*1277*	*1123*	*1138*	*837*	*862*	*728*	*747*	*564*	*872*	*686*	*718*	*735*	*701*
5C2	*Land converted to Grassland*	*-7228*	*-7346*	*-7458*	*-7585*	*-7695*	*-7797*	*-7897*	*-8017*	*-8118*	*-8136*	*-8175*	*-8218*	*-8333*	*-8435*	*-8542*	*-8625*	*-8720*	*-8767*
5C (liming)	*Liming of Grassland*	*652*	*815*	*825*	*543*	*610*	*719*	*647*	*718*	*523*	*431*	*301*	*281*	*265*	*369*	*331*	*313*	*313*	-*270*
5D	**Wetland**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	*Wetland remaining Wetland*	*IE*	*IE*	*IE*	*IE*	*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*	*IE*	*IE*	*IE*	*IE*
5E	**Settlements**	**7074**	**6989**	**6907**	**6848**	**6803**	**6722**	**6707**	**6710**	**6669**	**6605**	**6567**	**6543**	**6475**	**6460**	**6423**	**6384**	**6329**	**6330**
5E1	*Settlements remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5E2	*Land converted to Settlements*	*6972*	*6897*	*6825*	*6770*	*6724*	*6655*	*6630*	*6620*	*6580*	*6517*	*6476*	*6446*	*6392*	*6373*	*6341*	*6307*	*6263*	*6259*
5F	**Other-Land**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
5F1	*Other-Land remaining Other-land*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5F2	*Land converted to Other-Land*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5G	**Other activities**	**-1682**	**-1416**	**-1109**	**-1003**	**-793**	**-1041**	**-1185**	**-1365**	**-1468**	**-1513**	**-1268**	**-834**	**-267**	**42**	**368**	**-140**	**-544**	**-1293**
5G1	*Harvested Wood Products*	**-1682**	**-1416**	**-1109**	**-1003**	**-793**	**-1041**	**-1185**	**-1365**	**-1468**	**-1513**	**-1268**	**-834**	**-267**	**42**	**368**	**-140**	**-544**	**-1293**
5A2, 5C2, 5E2	*Biomass burning Gg CH_4 a^{-1}*	*0.797*	*0.904*	*0.619*	*0.626*	*0.608*	*1.407*	*1.019*	*1.198*	*0.907*	*0.832*	*1.185*	*1.474*	*1.269*	*1.209*	*1.183*	*1.010*	*1.373*	*1.467*
5A2, 5C2, 5E2	*Biomass burning Gg N_2O a^{-1}*	0.0055	0.0054	0.0043	0.0043	0.0042	0.0097	0.0070	0.0082	0.0062	0.0057	0.0081	0.0101	0.0087	0.0083	0.0081	0.0069	0.0099	0.0101
5A2	*N fertilization of forests Gg N_2O a^{-1}*	0.0207	0.0218	0.0209	0.0144	0.0127	0.0126	0.0107	0.0099	0.0103	0.0089	0.0090	0.0079	0.0071	0.0072	0.0060	0.0051	0.0043	0.0040
Information Item	*Forest Land converted to other*	*319*	*319*	*319*	*312*	*321*	*319*	*341*	*351*	*356*	*414*	*467*	*520*	*486*	*484*	*468*	*468*	*446*	*435*
Information Item	*Grassland converted to other land*	*18275*	*18125*	*17975*	*17835*	*17719*	*17625*	*17535*	*17438*	*17372*	*17323*	*17319*	*17329*	*17316*	*17265*	*17221*	*17164*	*17076*	*17003*

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2. Inventory estimates for the Kyoto Protocol (WP 1.2)

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2.1 Introduction

CEH first produced a voluntary submission of CRF tables for activities under the Kyoto Protocol (Articles 3.3 and 3.4) in April 2007. Supplementary information on these tables was included in the 2007 National Inventory Report submission (Annex 10) in accordance with Decisions 15/CP.10 (FCCC/CP/2004/10/Add.2). Progress in the development of methodologies for estimating emissions and removals from such activities are described here and have been submitted to the UN. The UK has opted to use entire commitment period accounting (2008-2012) for activities under Article 3.3 and 3.4, reporting in 2014. However, we are required to report activity estimates from 2010 onwards.

Article 3.3 of the Kyoto Protocol requires Parties to account for Afforestation, Reforestation and Deforestation (ARD) since 1990 in meeting their emissions reduction commitments using a consistent forest definition. The UK definition of forest was agreed with the Forestry Commission and has the following single minimum values:

- a minimum area of 0.1 hectares;
- a minimum width of 20 metres;
- tree crown cover of at least 20 per cent, or the potential to achieve it;
- a minimum height of 2 metres, or the potential to achieve it.

These single minimum values are used for reporting UK forestry statistics (Forestry Commission, 2006) and the UK's greenhouse gas inventory submitted under the UNFCCC. The definitions are consistent with information provided by the UK to the FAO. However, if an international enquiry uses a different minimum definition, for example 0.5 ha in the Global Forest Resource Assessment 2005, the UK areas are adjusted (explicitly or implicitly) to this different definition (FAO, 2005).

The UK has chosen to elect Forest Management (FM) as an activity under Article 3.4. For the UK, credits from Forest Management are capped in the first commitment period at 0.37 MtC (1.36 $MtCO_2$) per year, or 6.78 $MtCO_2$ for the whole commitment period.

2.2 Consistency of Kyoto Protocol reporting with UNFCCC GHGI reporting

The areas of forest land reported for AR and FM under the Kyoto Protocol equal the area reported under 5.A.2 (Land converted to Forest Land) in the UNFCCC greenhouse gas inventory. The Afforestation/Reforestation area is land that has been converted to forested land since 1990 (inclusive), while the Forest Management area is the area converted to forest land between 1921 and 1989. In the UK Land converted to Forest Land is considered to stay in that category beyond the IPCC 20 year default period in order to take account of the long term soil carbon dynamics. Deforestation since 1990 is taken to be the land area permanently converted from forest land to either grassland or settlement (conversion to cropland is estimated to be negligible based on land use surveys). All ARD and FM definitions are consistent with those used in the UNFCCC inventory and updates to methodologies over time have been back-calculated to 1990 to ensure consistency over time.

The afforestation and reforestation datasets are provided by the Forestry Commission and the Forest Service of Northern Ireland (the national forestry agencies) and are consistent with the definition of forest given above. There is an assumption of restocking after harvesting on the national estate, although open habitat can make up 13-20% of stand area on restocking. Therefore, Afforestation and Reforestation under Article 3.3 can be considered together. A felling license is required for felling outside the national forest estate; there is a legal requirement to restock under such a license unless an unconditional felling license is granted (in which case this would be formally reported as deforestation). Information on deforestation activities is assembled from data provided by the Forestry Commission and by the Ordnance Survey (the national cartographic agency) through the UK government. To the best of knowledge, these definitions have been applied consistently over time, although larger uncertainties are associated with deforestation estimates compared with afforestation estimates.

2.3 Land-related information

Spatial assessment unit used

The spatial assessment units used for the voluntary submission of the Kyoto Protocol CRF tables in 2009 are the four countries of the UK: England, Scotland, Wales and Northern Ireland. A methodology for reporting using units of 20 x 20km grid cells (Figure 2-1) is in development, where the location of ARD and FM land will be statistically determined for the 852 grid cells covering the UK (GPG LULUCF Reporting Method 1). Each 20x20km cell has a unique identification code produced from the coordinates of the lower left corner of the cell (using the Ordnance Survey British National Grid projection).

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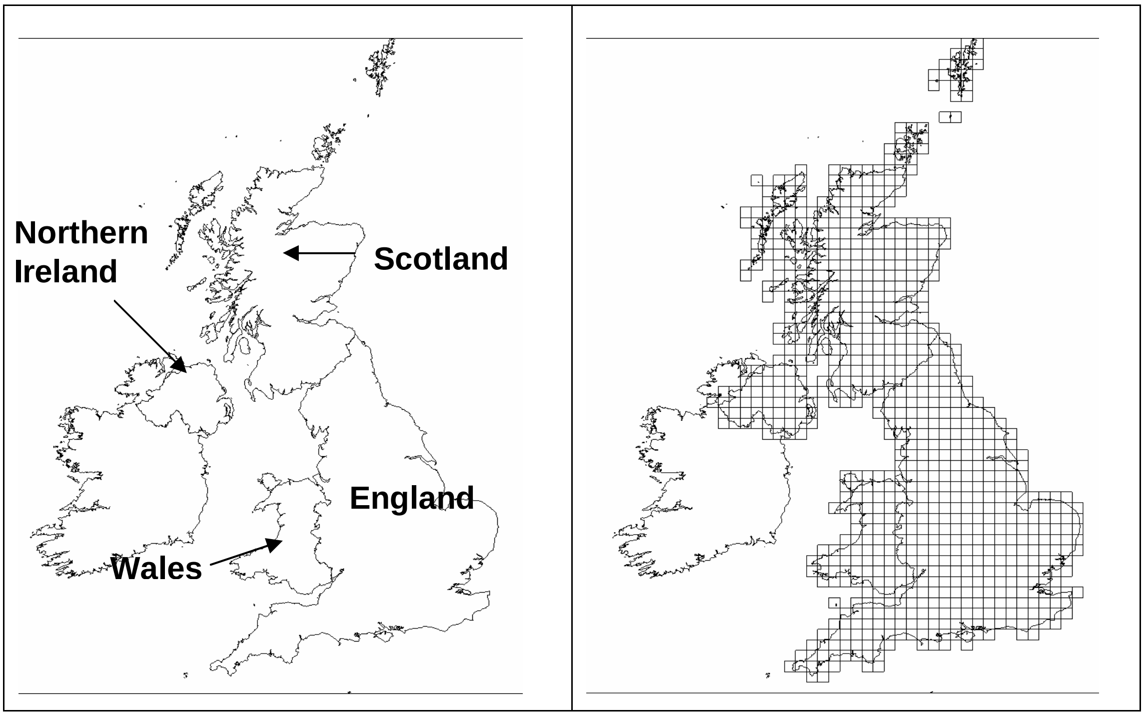

Figure 2-1: Spatial units used for reporting Kyoto protocol LULUCF activities: (left) the four countries of the UK, (right) 20 x 20km grid cells covering the UK.

Methodology used to develop the land transition matrix

Several datasets are either available, or will become available, for the assessment of ARD and FM activities in the UK (Table 2-1). The UK GHGI currently uses the national planting statistics from 1921 to the present, which are provided by the Forestry Commission and the Northern Ireland Forest Service for each of the countries in the UK. This data is used for the estimation of AR and FM in the LULUCF tables. Estimates of Deforestation are made using the Unconditional Felling Licences and the Land Use Change Statistics (LUCS), a survey of land converted to developed use.

The relationship between the currently used datasets and the land transition matrix is shown in Table 2-2. With current methods it is not possible to assess the split in the Deforestation area between areas under Afforestation/ Reforestation and Forest Management although it is reasonable to assume that there will be little Deforestation on areas afforested since 1990. We are in the process of progressing from the situation shown Table 2-2 to that shown in Table 2-3 (using 20km grid scale datasets).

Table 2-1: Data sources on ARD and FM activities (additional data sources may become available in the future)

Activity	Dataset	Available scale	Time period	Details
AR & FM	Annual planting statistics	Country (England, Scotland, Wales, Northern Ireland)	1921-present	New planting on previously non-forested land. Updated annually. Categorized into conifer and broadleaved woodland.
AR	Grant-aided woodland database	Local administrative unit/NI counties	1995-present	Private woodland planted with grant aid since 1995. Categorized into conifer and broadleaved planting.
AR & FM	Forestry Commission management database	20km grid cells	1995-present	Database of state woodland planting since 1995, indicating the rotation (1st rotation will be Afforestation, 2nd or greater rotations are restocking). Categorised by species.
AR & FM	National Inventory of Woodland and Trees (NIWT)	20km grid cells (sample statistics)	1995	Grid cell database includes the area and planting decade of each species within the grid cell. A digital map of woodland over 2ha is also available.
ARD, FM	*NIWT2*	*20km grid cells (sample statistics)*	*Planned for 2009-2017*	*Update of the 1995 NIWT. A partial repeat of the grid cell analysis should be available by 2013. An update of the digital map will be available, initially from 2009, which can be used to asses deforestation since NIWT1.*
D	Forestry Commission Unconditional Felling Licence data	England only (data from other countries should become available)	1990-2002	Unconditional Felling Licences are issued for felling without restocking. Used to estimate deforestation in rural areas (primarily for heathland restoration). English data is extrapolated to GB scale and to current reporting year. Omits felling for development purposes, e.g. construction of wind turbines.
D	Land Use Change Statistics (survey of land converted to developed uses)	England only (data from other countries should become available)	1990-2003 (updated in 2007)	Estimates of the conversion of forest to urban/developed land use. Based on Ordnance Survey map updates, identifying changes through aerial surveys and other reporting, expected to capture most changes within five years. English data is extrapolated to GB scale and to current reporting year.

Table 2-2: Land transition matrix using national datasets

To From	Article 3.3		Article 3.4
	Afforestation/ Reforestation	Deforestation	Forest Management
Afforestation/ Reforestation	New planting since 1990 (national planting statistics).	Not estimated at present.	
Deforestation		Unconditional felling licences/LUCS	
Forest Management		Unconditional felling licences/LUCS	Forest planted 1921-1989 (national planting statistics) and NIWT.

Table 2-3: Proposed land transition matrix with the 20km grid for end of commitment period accounting

To From	Article 3.3		Article 3.4
	Afforestation/ Reforestation	Deforestation	Forest Management
Afforestation/ Reforestation	1990-1995: national planting statistics, spatially distributed in proportion to NIWT data on planting in 1990s. 1995-2012: FC management database and grant-aided woodland database.	Comparison between NIWT and NIWT2 forest cover map. Unconditional felling licences.	
Deforestation		NIWT vs. NIWT2 forest cover map.	
Forest Management		NIWT vs. NIWT2 forest cover map. Unconditional felling licences	Use NIWT and NIWT2.

Activity-specific information

Carbon uptake by UK forests is estimated by the carbon accounting model, C-Flow, as described in the Forest Land section in Chapter 1. The model estimates the net change in pools of carbon in standing trees, litter and soil in conifer and broadleaf forests. All pools and fluxes are included although the below-ground biomass and dead wood carbon pools are currently not reported separately but included in the soil and litter carbon pools respectively. The C-Flow model was originally set up in Microsoft Excel to run at the national scale. The model has now been moved to the Matlab programming environment and modified to run with spatially disaggregated input data (20km grid cells in this instance). C-Flow is used to estimate carbon stock changes from Article 3.3 Afforestation/Reforestation and Article 3.4 Forest Management.

The next stage is the construction of the activity dataset on an annual basis from the various spatially disaggregated data sources. This has initially been done for Article 3.3 Afforestation/Reforestation. The ArcMap geographical information system was used for this work. There are still some issues to resolve between national and regional annual planting totals, so at present the spatially disaggregated data is used to weight the distribution of the national planting totals across the 20km cells, rather than using the spatially disaggregated data directly.

Great Britain state and private planting 1990-1995. Records of state/private planting in the decade since April 1990 were extracted from the National Inventory of Woodland and Trees (NIWT) for each 20km cell. These records include large areas of restocking as well as new planting, so the area of new planting per cell was estimated using ratios of new planting to restocking for broadleaf/conifer and state/private woodland. These ratios were obtained from published forest statistics reports and the Forestry Commission planting database (1995 onwards). The areas of planting were used to assign a weight to each cell for each country (England, Scotland and Wales): these weights were then used to distribute the national annual planting area (1990-1995) across all cells.

Northern Ireland state and private planting 1990-1996. The NIWT does not cover Northern Ireland so the only planting areas are available are the national ones. Forest cover is not evenly distributed in Northern Ireland, with the dominant conifer plantations concentrated in the western uplands. The national planting areas were distributed across the country using a 20 km cell weighted distribution based on the size and location of state-owned forests (Forest Service Facts & Figures 2001/02 and the Forest Service website http://www.forestserviceni.gov.uk/). This approach is not ideal, because the forest distribution only reflects that of state forests in 2001, and more appropriate data will be sought.

Great Britain state planting 1995- present. The Forestry Commission Sub-Compartment Database (SCDB) was used to estimate state afforestation from 1995 onwards. The SCDB is the stand management database for state-owned and managed forest, containing information on species, age, yield class and management, and spatially referenced by 20km cells. Records of annual new planting areas were extracted for conifer and broadleaf planting. The areas of planting were used to assign a weight to each cell for each country (England, Scotland and Wales): these weights were then used to distribute the national annual planting area across all cells.

Great Britain private planting 1995- present. Woodland Grant Schemes (WGS) is the schemes by which the government (i.e. the Forestry Commission) encourages planting and management of private woodland. They covers almost all private woodland planting since 1995: there is a small amount of non-grant aided woodland (mostly in England) which is assumed to be broadleaved natural regeneration but we have no further information on the management or permanence of this area. Information on planting under the WGS is available for each country in Great Britain, split by new planting and restocking. The information provided is the area for which new planting grants have been paid and the planting has actually been completed. The FC will not pay grants prior to the planting taking place so we know that the areas are therefore all stocked. Conifer and broadleaf planting is split by NUTS4 administrative regions (local authority areas). The planting areas were re-assigned in proportion to the appropriate co-incident 20km cells. The areas of planting were used to assign a weight to each cell for each country (England, Scotland and Wales): these weights were then used to distribute the national annual planting area across all cells.

Northern Ireland state and private planting 1996-present. Information is available on the areas planted annually under the Northern Ireland Woodland Grant Scheme since 1996. These are reported by the old county districts for 1996-2006 (Antrim, Armagh, Down, Fermanagh, Derry and Tyrone) and by NUTS4 district for 2006-2007. The planting areas were re-assigned in proportion to the appropriate co-incident 20km cells. Information on the relative distribution of conifer and broadleaf planting was only available in 2006, otherwise the same distribution is assumed for both forest types. No specific information was available on the distribution of state planting. The 20km cell weighting for private woodland planting was used to distribute the national annual planting area across all cells. The methods and data sources for Northern Ireland will be kept under review.

These separate activity datasets were combined into spatial annual planting series for conifer and broadleaf woodland from 1990 to 2007. The maps of cumulative planting to 2007 are shown in Figure 2-2. The differences in afforestation distribution between conifer and broadleaf woodland and between countries can be seen clearly.

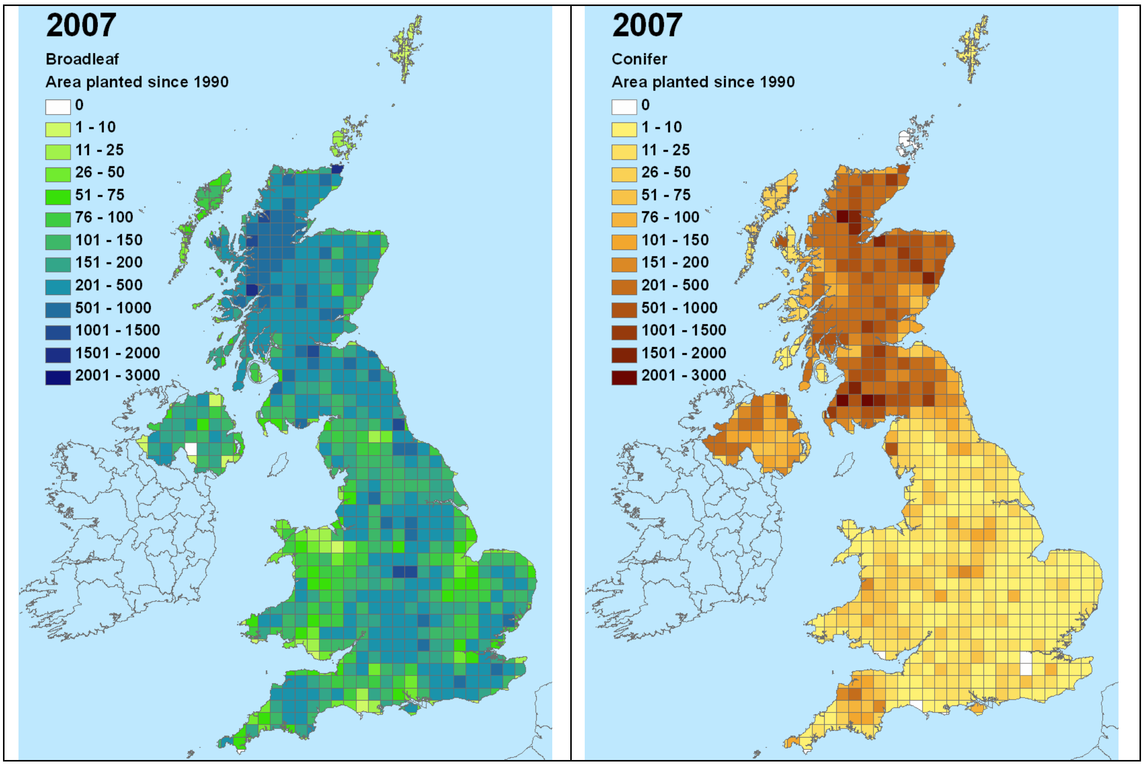

Figure 2-2: Cumulative planting 1990-2007 of broadleaf and conifer woodland, ha

The combined spatial planting series were run in the new Matlab version of the CFlow accounting model. This produces preliminary estimates of carbon stock changes due to Article 3.3 Afforestation (Figure 2-3). It should be noted that this methodology still needs further development. The initial results are interesting, with most of the carbon sink located in Scotland although the National Forest (in the English Midlands), where there has been extensive planting in the past decade, also shows up on the map. The small carbon source in the Shetland Islands (in the far north of the UK) is probably due to planting disturbance of organic soils, although this requires further investigation.

The methods currently used for the reporting of Article 3.3 Deforestation and Article 3.4 Forest Management are those reported in the NIR. Progress in method development for these activities will be described in future reports.

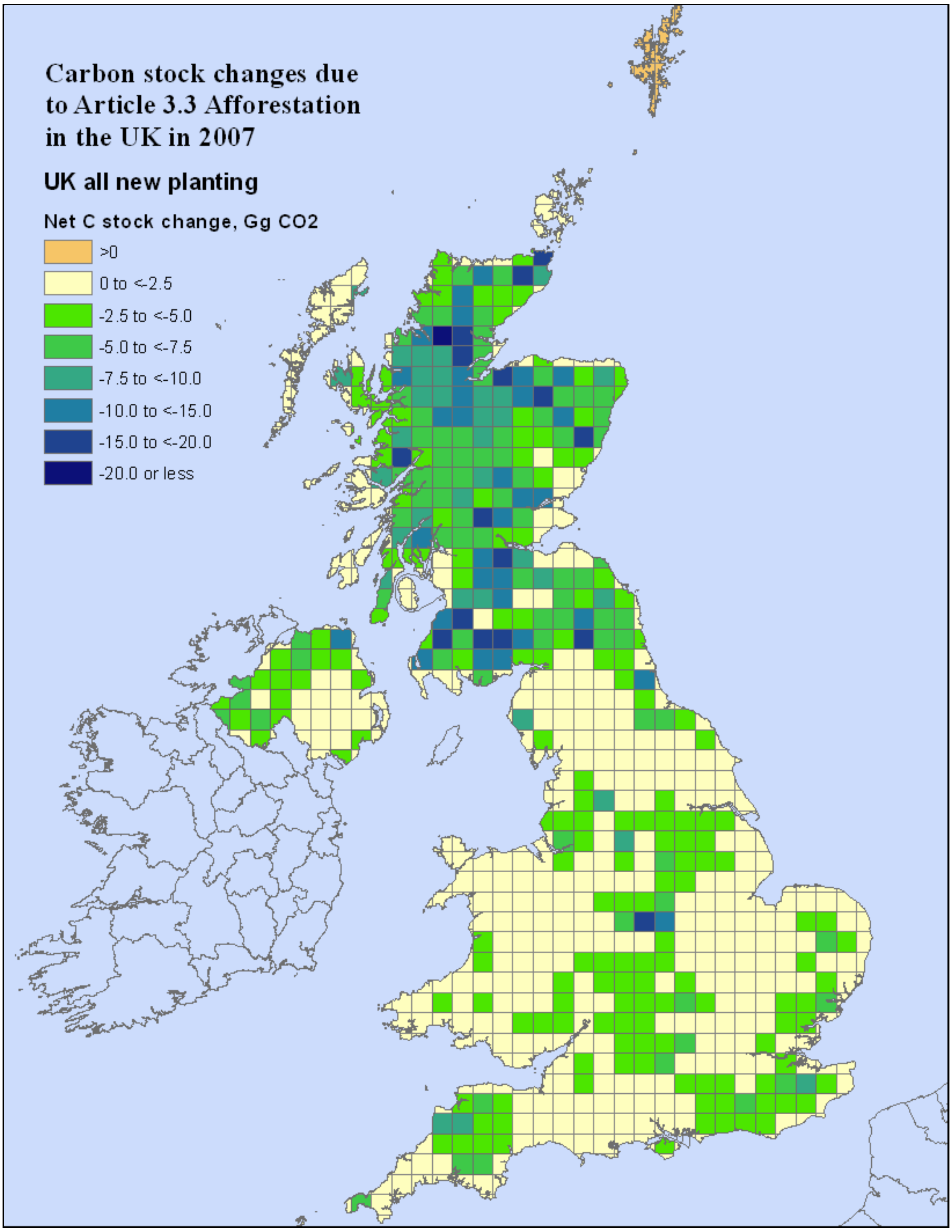

Figure 2-3: Carbon stock changes due to Article 3.3 Afforestation in the UK 1990-2007, Gg CO2

The area included in Forest Management only includes those areas of forest that were newly planted between 1921 and 1990 (1394 kha or c.50% of the UK forest area). The area of forest established before 1920 (c. 820 kha) is reported in the CRF for the national greenhouse gas inventory but is assumed to be in carbon balance, i.e. zero flux. Uncertainty as to the management and date of first establishment of pre-1921 woodlands (which are predominantly broadleaf) makes it difficult to estimate appropriate model parameters. The omission of pre-1920 forests will have no effect on the number of credits that the UK can claim under Article 3.4, as these are capped for the first commitment period.

Nitrous oxide emissions from N fertilization of newly planted forest land on poor soils are now included (see Chapter 1). The Forestry Commission has estimated liming of forests and N fertilisation of established forest land to be negligible due to economic factors, so emissions from these activities are not currently estimated. Emissions of N2O from areas in Forest Management due to the drainage of soils are not currently estimated, although a methodology is under consideration (Chapter 6).

Emissions of greenhouse gases due to biomass burning are estimated for Deforestation. Biomass burning should diminish as the use of woodfuel as a source of bioenergy becomes more commonplace. Emissions due to forest wildfires are now included (see Chapter 1 for further details). At present, it is assumed that all wildfires occur on Forest Management land. Assessing the impact of wildfires on AR forests is methodologically complex under the UK's current approach and wildfires would only affect a very small area of AR land area (less than 1% since 1990) if the burnt areas are distributed in proportion to forest. It can be assumed that wildfires will not result in permanent deforestation. This area will be kept under review.

2.4 Article 3.3

Under the current methodology, the Forestry Commission and the Forest Service of Northern Ireland provide annual data on new planting (on land that has not previously been forested). This information is provided for each country in the UK and the time series extends back before 1990. Data are provided for both state and private woodlands: the private woodland planting is divided between grant-aided and non-grant-aided. Estimates of non-grant-aided woodland planting and restocking are reported annually, for inclusion in planting statistics, although the Forestry Commission have doubts about their completeness and accuracy. Their assessment is that non-grant-aided new woodland has arisen by natural regeneration and is all broadleaved. This assumption can be verified against the NIWT2 at a later date. Only state and grant-aided woodland areas are currently included in the assessment of Article 3.3 activities as these are directly human-induced.

The data sources and method for estimating AR fluxes have been described above. The statistics are reported by planting year, which runs from the 1st April of the previous year to the 31st March of the reported year, i.e. the 2001 planting year was 1st April 2000 to 31st March 2001. These statistics are adjusted to calendar years in order to be compliant with the Kyoto Protocol regulations. This adjustment has the effect of slightly smoothing the planting series and has no effect on the area of forest planted overall. The annual planting series drives the model C-Flow, which produces outputs at the annual scale.

The data sources used for estimating Deforestation do not allow for confusion between harvesting or forest disturbance and deforestation. The unconditional felling licences used for the estimation of rural deforestation are only given when no restocking will occur, and the survey of land converted to developed use describes the conversion of forest land to the settlement category, which precludes re-establishment. The NIWT2, which will be partially completed by the end of the first commitment period, will be used to verify deforestation estimates made using these data sources. Emissions from forest wildfires were included in the UNFCCC inventory for the first time in 2008. Damage from windblow is not reported in the UNFCCC inventory, although it does occur in the UK (FAO, 2005; Forestry Commission, 2002). There are currently insufficient data to include the effects of these disturbances in the inventory although this is being kept under review and a methodology will be developed in time.

Restocking is assumed for forest areas that have lost forest cover through harvesting or forest disturbance, unless there is deforestation as described above. As such, information on the size and location of forest areas that have lost forest cover is not explicitly collected. However, it should be possible to assess such areas through the comparison of the NIWT and NIWT2 at the end of the first commitment period.

Projections of emissions/removals associated with ARD since 1990 have not yet been completed. These projections for Mid, Low and High emission scenarios for the UK, England, Scotland, Wales and Northern Ireland are available on request from Amanda Thomson. The expected emissions/removals from ARD 2007-2012 from existing activities are reported in Appendix 4.

2.5 Article 3.4

Countries could elect to use net sinks within Forest Management, Cropland Management, Grassland Management and/or Re-vegetation to offset emissions within the first commitment period (2008-2012). The UK elected to use only Forest Management in January 2006, as the uncertainties associated with estimating emissions and removals due to Cropland and Grassland Management were considered to be too large for the purposes of achieving acceptable emission reductions under the Protocol (Re-vegetation is not relevant in the UK context).

All managed forests (planted between 1921 and 1989) are included in the Forest Management category. The C-Flow model is used to calculate emissions from this forest area after 1990 that have arisen from thinning, harvesting and restocking. A current research project is examining the impact of management upon carbon stock changes in UK forests in more detail (Work Package 2.3). The removals of carbon dioxide by land under Forest Management predicted to 2020 for the Mid scenario are shown in Figure 2-4. Removals exceed the cap for all years except 2020.

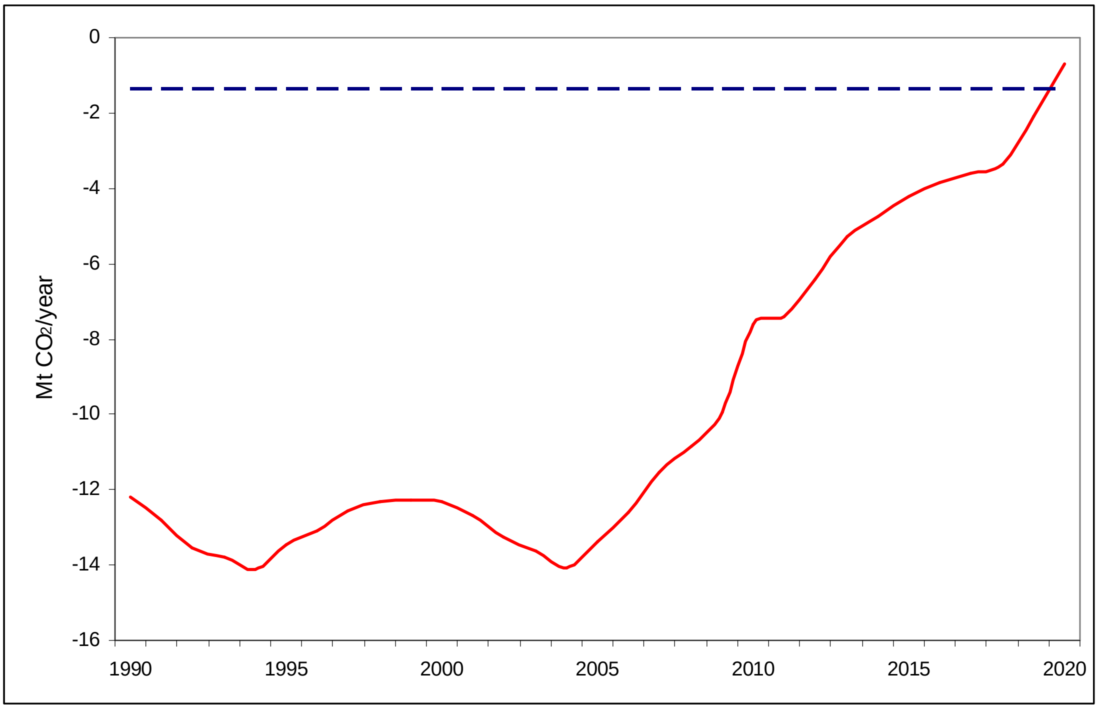

Figure 2-4: Kyoto Protocol Article 3.4: Removals and emissions associated with Forest Management for the MID scenario. The UK cap of -0.37 MtC/year (-1.36 Mt CO2 eq.) is shown by the broken line.

Forest Management under the Protocol is defined as a system of practices for stewardship and use of forest aimed at fulfilling relevant ecological, economic and social functions of the forest in a sustainable manner. The UK has a system of certification for sustainable woodland management under the Forest Stewardship Council (FSC). Forest statistics published in 2006 by the Forestry Commission record that 73% of softwood removals in 2005 were from certified sources. Such removals will almost entirely come from post-1920 conifer woodland reported under Forest Management. The management practices in certified woodlands are reviewed annually. All state-owned forests are certified and an increasing proportion of non-state-owned woodlands are becoming certified. The total certified area in March 2008 was 1266 kha (Forestry Commission, 2008). This does not include all woodland that is managed in a sustainable manner, such as smaller or non-timber producing woodlands where certification is not considered worthwhile. In particular, it may omit many broadleaved woodlands even though they are managed for their social and environmental benefits (Forestry Commission, 2002). In the UK's country report to the Global Forest Resource Assessment 2005 (FAO, 2005) 83% of UK forests are managed for production, 18% are managed for conservation of biodiversity (these have protected status) and 55% have a social service function (public access).

2.6 Article 3.7

Under Kyoto Protocol Article 3.7 countries with a net emission in 1990 from the LULUCF Sector must count that part of the emission due to deforestation for estimating "Base Year Emissions". These "Base Year Emissions" then become the basis for the emission allowance for that country during the first commitment period (2008-2012). In 1990 the UK LULUCF Sector is estimated to have been a net emitter, therefore Article 3.7 applies. The deforestation emission in 1990 has been taken to be that associated with all deforestation prior to and 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 estimate of deforestation emissions in 1990 in the 2004 GHG Inventory (the estimate used in the Assigned Amount) was 366 Gg CO_2-equivalent (including CH_4 and N_2O emissions). The estimate of 1990 deforestation emissions in the 2006 inventory is 319 Gg CO_2-equivalent, as revisions in the deforestation activity data have affected estimates of emissions. However, this change will not affect the UK's Assigned Amount which is fixed to the 2004 inventory estimate.

2.7 References

Forestry Commission (2008). Forestry Statistics 2008: A compendium of statistics about woodland, forestry and primary wood processing in the United Kingdom. http://www.forestry.gov.uk/pdf/ForestryStatistics2008.pdf/$FILE/ForestryStatistics2008.pdf

3. Inventory estimates for the Devolved Administrations of the UK (WP 1.3)

The current LULUCF inventory methods use a combination of top-down and bottom-up approaches, based on activity data for each of the UK constituent countries and the UK as a whole, as described in Chapter 1. As a result of this approach, estimates of emissions and removals from LULUCF activities are automatically produced at the Devolved Administration and UK scale. The emissions scenarios used for the High, Mid and Low scenarios for each country are described in Chapter 4. The summary emissions/removals estimates 1990-2020 for each country are given in Appendix A.1 and the sectoral tables for each country are in Appendix A.3. Estimates of emissions/removals by post-1990 activities under Article 3.3 and 3.4 of the Kyoto Protocol for each country are given in Appendix A.4.

4. Projections of emissions and removals from the LULUCF sector to 2020 (WP 1.4)

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4.1 Introduction

The UK is required to periodically report projections of emissions/removals from LULUCF activities to 2020 to the European Union Monitoring Mechanism and the UN Framework Convention on Climate Change. Projections of emissions for years from 2007 to 2020 have been made for each activity for the UK and for each of the Devolved Administration areas of England, Scotland, Wales and Northern Ireland. "Business As Usual" (Mid), high emission (High) and low emission scenarios (Low) were developed for each activity. The UK fluxes for each scenario are presented in Appendix A.1. A summary table of the net UK flux under the different emission scenarios is shown in Table 4-1.

Table 4-1: UK Inventory (1990 to 2007) and projected (to 2020) Emissions and Removals data (GgCO2/year). (-ve sign indicates Removal)

Year	Net (LOW)	Net (MID)	Net (HIGH)
1990	2929	2929	2929
1995	1242	1242	1242
2000	-339	-339	-339
2005	-1934	-1934	-1934
2010	-2556	-1229	252
2015	-2827	912	4248
2020	-3554	2724	8097

4.2 Basis for projections

The basis for projection of each activity varies between England, Scotland, Wales and Northern Ireland as appropriate. These assumptions are described in Table 4-2, Table 4-3, Table 4-4 and Table 4-5 respectively.

4.3 Results for projections of LUCF Categories

The projections for Mid, Low and High emissions scenarios for the UK, England, Scotland, Wales and Northern Ireland are presented in Appendix A.1. The UK emissions, removals and net flux for each scenario for CO_2, CH_4 and N_2O are plotted in Figure 4-1, Figure 4-2 and Figure 4-3. The reporting format of the GPG on LULUCF is used for these data. Projections to 2020 of the Forest Land, Cropland, Grassland and Settlements (Urban) net fluxes of carbon dioxide from the atmosphere in the United Kingdom are plotted in Figure 4-4. Projections to 2020 of net fluxes of carbon dioxide from the atmosphere in England, Scotland, Wales and N. Ireland are plotted in Figure 4-5. Projections of net fluxes for Forest Land, Cropland, Grassland and Settlements for each scenario for the individual Devolved Administrations are plotted in Figure 4-6, Figure 4-7, Figure 4-8 and Figure 4-9. Total fluxes of CH_4 and N_2O for each country are shown in Figure 4-10 and Figure 4-11.

The long harvest cycles for forest plantations means that the different assumptions made for Afforestation scenarios will have no effect on Harvested Wood Product emissions/removals before 2020. Therefore there is no difference in the projection scenarios between 2008 and 2020.

The projection assumptions for N_2O emissions from N fertilization of new forests are the same as the assumptions for the Afforestation scenarios. The N_2O emissions are inversely related to the Afforestation removals because more new planting results in more N fertilization.

Table 4-2: Scenario assumptions for projection of LULUCF net Emissions (England)

Scenario assumption: England			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
CO_2			
Afforestation (5A)	UK Total of 30 kha/yr from 2008 split in proportion to 2007 planting (11.5 kha/yr)	Conifer and broadleaf planting from 2008 assumed to be as in 2007 (total of 3.1 kha/yr).	Conifer and broadleaf planting from 2008 assumed to be 0 ha/yr.
Wildfires (5A)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2007 trend	Autoregressive model (10 terms) fitted to 1990 to 2007 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2007 trend
Deforestation (biomass burning) (5C, 5E)	As MID but trend adjusted to lower value (95% C.L) of 1990-2006 trend	Autoregressive model (10 terms) fitted to 1990-2006 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990-2006 trend
Land Use Change (Soils) (5B, 5C, 5E)	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives minimum values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives mean values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives maximum values from 2008
Peat extraction (5C)	As MID but trend adjusted to lower value (95% C.L) of 1990-2006 trend	Autoregressive model (10 terms) fitted to 1990-2006 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990-2006 trend
Liming (5B, 5C)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2005 trend	Autoregressive model (10 terms) fitted to 1990 to 2005 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2005 trend
Lowland drainage (5B)	Flux changes from 2008 at modelled rate of change for 1990-2000 (1 Gg C/yr)	Flux changes from 2008 at modelled rate of change	Flux changes from 2008 value at modelled rate of change for 2010-2020 (2 Gg C/yr)
Non-forest biomass (5B, 5C, 5E)	Flux remains at 2007 value	Flux remains at 2007 value	Flux remains at 2007 value
Harvested Wood Products (5G)	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.
CH_4	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)
N_2O	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.

Table 4-3: Scenario assumptions for projection of LUCF net Emissions (Scotland)

Scenario assumption: Scotland			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
CO_2			
Afforestation (5A)	UK Total of 30 kha/yr from 2008 split in proportion to 2007 planting (14.6 kha/yr)	Conifer and broadleaf planting from 2008 assumed to be as in 2007 (total of 4.0 kha/yr).	Conifer and broadleaf planting from 2008 assumed to be 0 ha/yr.
Wildfires (5A)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2007 trend	Autoregressive model (10 terms) fitted to 1990 to 2007 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2007 trend
Deforestation (biomass burning) (5C, 5E)	As MID but trend adjusted to lower value (95% C.L) of 1990-2007 trend	Autoregressive model (10 terms) fitted to 1990-2007 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990-2007 trend
Land Use Change (Soils) (5B, 5C, 5E)	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives minimum values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives mean values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives maximum values from 2008
Peat extraction (5C)	As MID but trend adjusted to lower value (95% C.L) of 1990-2007 trend	Autoregressive model (10 terms) fitted to 1990-2007 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990-2007 trend
Liming (5B, 5C)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2005 trend	Autoregressive model (10 terms) fitted to 1990 to 2005 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2005 trend
Lowland drainage (5B)	NA	NA	NA
Non-forest biomass (5B, 5C, 5E)	Flux remains at 2007 value	Flux remains at 2007 value	Flux remains at 2007 value
Harvested Wood Products (5G)	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.
CH_4	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)
N_2O	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.

Table 4-4: Scenario assumptions for projection of LUCF net Emissions (Wales)

Scenario assumption: Wales			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
CO_2			
Afforestation (5A)	UK Total of 30 kha/yr from 2008 split in proportion to 2007 planting (1.7 kha/yr)	Conifer and broadleaf planting from 2008 assumed to be as in 2007 (total of 0.5 kha/yr).	Conifer and broadleaf planting from 2008 assumed to be 0 ha/yr.
Wildfires (5A)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2007 trend	Autoregressive model (10 terms) fitted to 1990 to 2007 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2007 trend
Deforestation (biomass burning) (5C, 5E)	As MID but trend adjusted to lower value (95% C.L) of 1990-2007 trend	Autoregressive model (10 terms) fitted to 1990-2007 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990-2007 trend
Land Use Change (Soils) (5B, 5C, 5E)	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives minimum values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives mean values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives maximum values from 2008
Peat extraction (5C)	NA	NA	NA
Liming (5B, 5C)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2005 trend	Autoregressive model (10 terms) fitted to 1990 to 2005 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2005 trend
Lowland drainage (5B)	NA	NA	NA
Non-forest biomass (5B, 5C, 5E)	Flux remains at 2007 value	Flux remains at 2007 value	Flux remains at 2007 value
Harvested Wood Products (5G)	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.
CH_4	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)
N_2O	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.

Table 4-5: Scenario assumptions for projection of LUCF net Emissions (Northern Ireland)

Scenario assumption: Northern Ireland			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
CO_2			
Afforestation (5A)	UK Total of 30 kha/yr from 2008 split in proportion to 2007 planting (2.2 kha/yr)	Conifer and broadleaf planting from 2008 assumed to be as in 2007 (total of 0.6 kha/yr).	Conifer and broadleaf planting from 2008 assumed to be 0 ha/yr.
Wildfires (5A)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2007 trend	Autoregressive model (10 terms) fitted to 1990 to 2007 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2007 trend
Deforestation (biomass burning) (5C, 5E)	NA	NA	NA
Land Use Change (Soils) (5B, 5C, 5E)	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives minimum values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives mean values from 2008	Annual area of land use change 2008-2020 assumed to be same as annual rate of change for 1990-2007. Monte Carlo simulation gives maximum values from 2008
Peat extraction (5C)	Flux remains at 2007 value (101.5 Gg CO_2)	Flux remains at 2007 value (101.5 Gg CO_2)	Flux remains at 2007 value (101.5 Gg CO_2)
Liming (5B, 5C)	As MID but trend adjusted to lower value (95% C.L) of 1990 to 2005 trend	Autoregressive model (10 terms) fitted to 1990 to 2005 UK data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2005 trend
Lowland drainage (5B)	NA	NA	NA
Non-forest biomass (5B, 5C, 5E)	Flux remains at 2007 value	Flux remains at 2007 value	Flux remains at 2007 value
Harvested Wood Products (5G)	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.	Same assumptions for Afforestation. No impact on HWP flux before 2020.
CH_4	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)	Same assumptions as for Wildfires and Deforestation (biomass burning)
N_2O	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.	Same assumptions as for Wildfires and Deforestation (biomass burning). Same assumptions as Afforestation for N fertilisation of new forests.

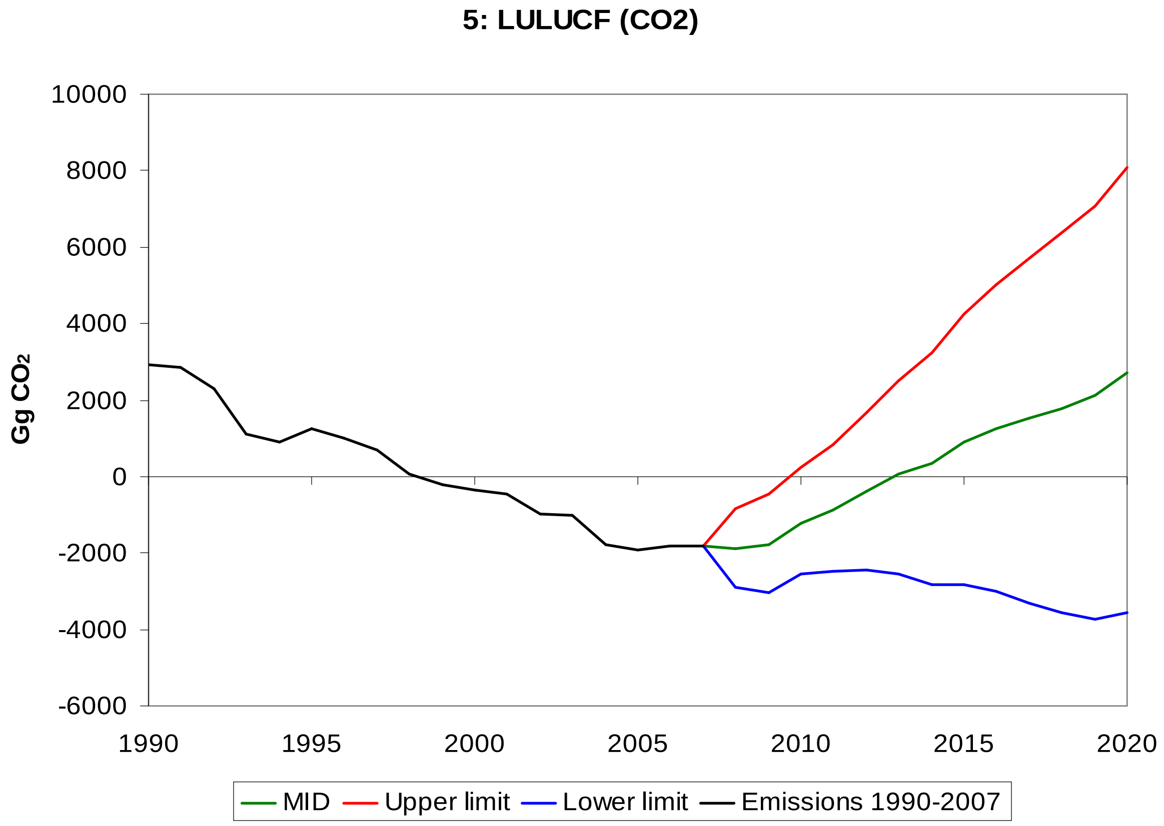

Figure 4-1: Projections to 2020 of Net Emissions and Removals of CO_2 from the atmosphere in the United Kingdom by Land Use, Land Use Change and Forestry for 3 future emissions scenarios

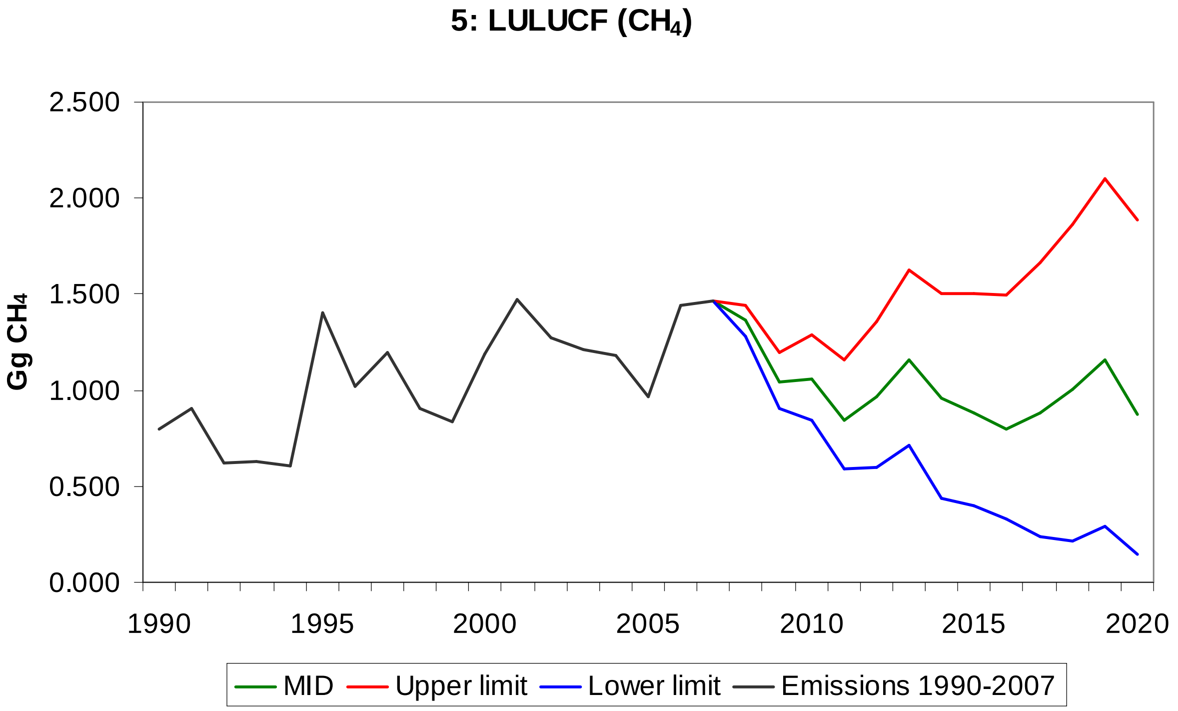

Figure 4-2: Projections to 2020 of emissions of CH_4 to the atmosphere in the United Kingdom by Land Use, Land Use Change and Forestry for 3 future emissions scenarios

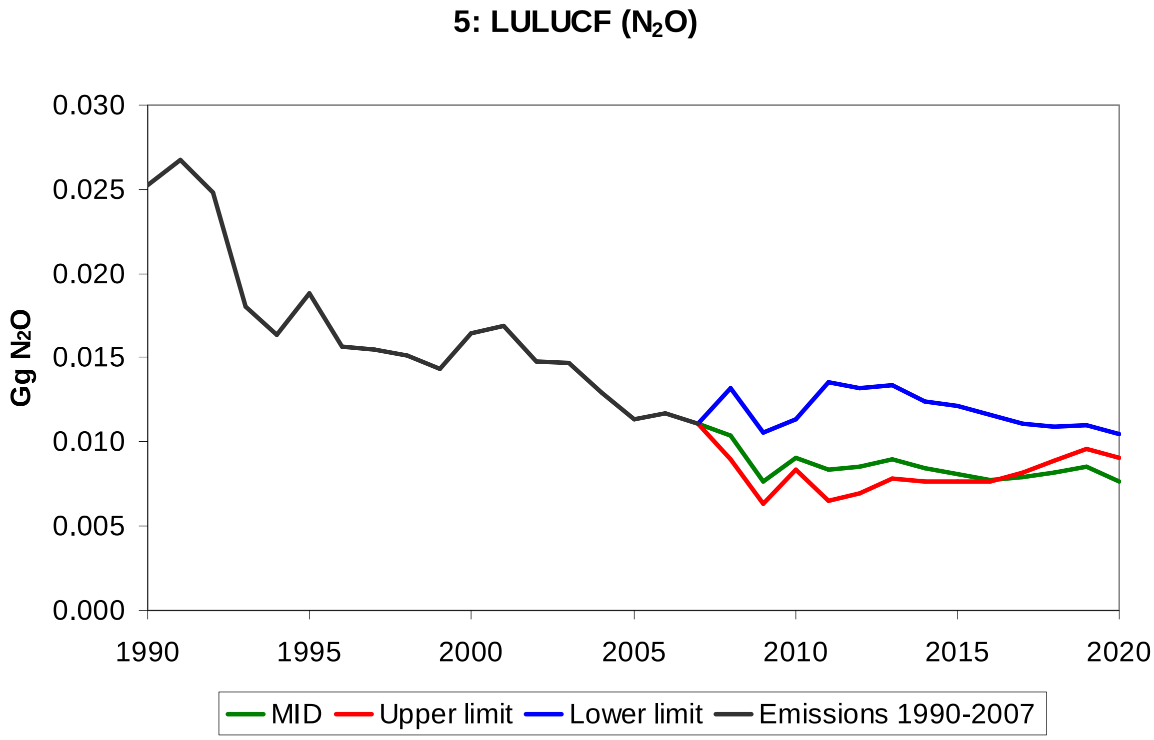

Figure 4-3: Projections to 2020 of emissions of N_2O to the atmosphere in the United Kingdom by Land Use, Land Use Change and Forestry for 3 future emissions scenarios

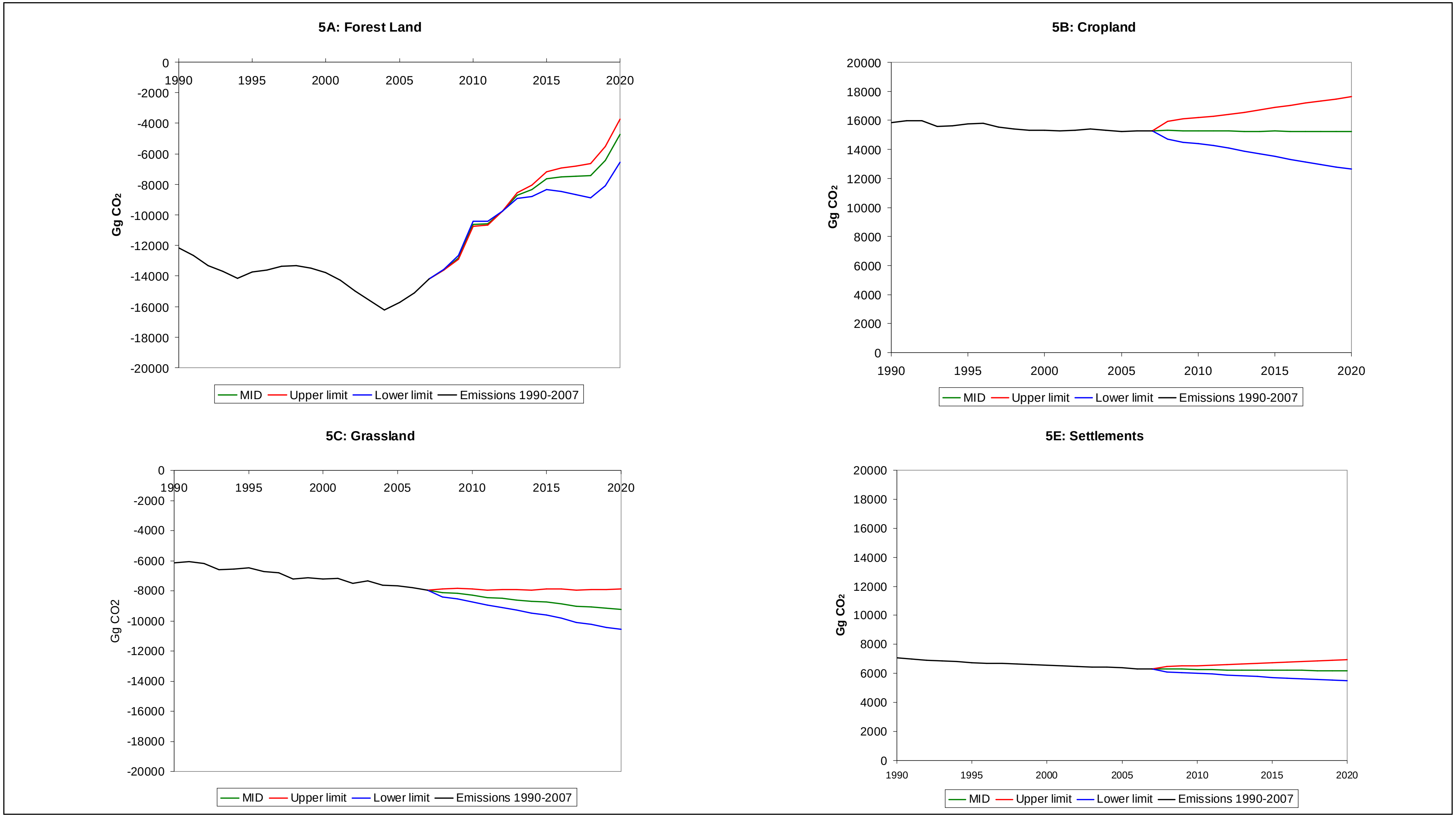

Figure 4-4: Projections to 2020 of Forest Land, Cropland, Grassland and Settlements (Urban) Net Emissions of carbon dioxide from the atmosphere in the United Kingdom by Land Use, Land Use Change and Forestry for 3 future emissions scenarios.

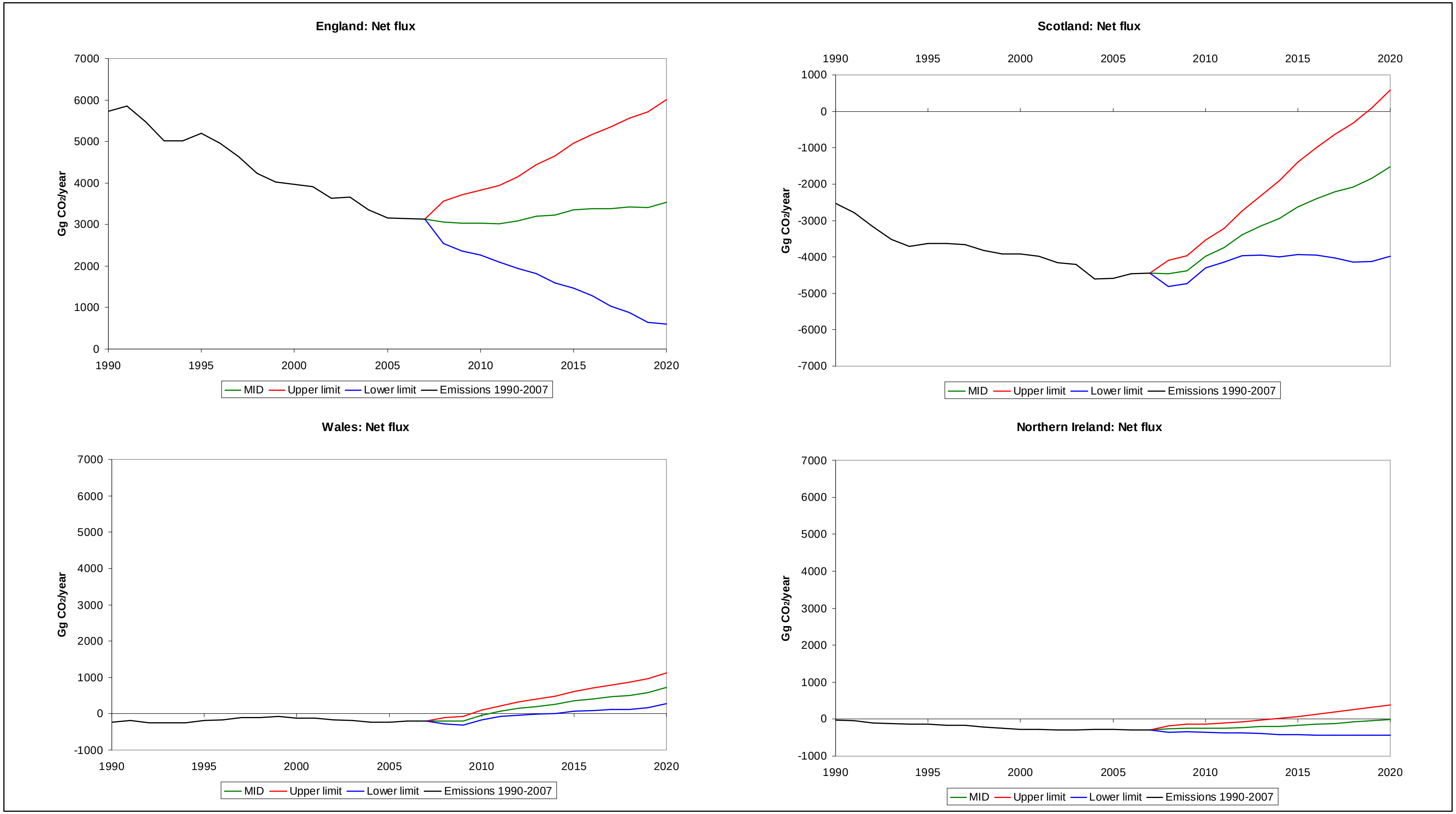

Figure 4-5: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by Land Use, Land Use Change and Forestry for 3 future emissions scenarios.

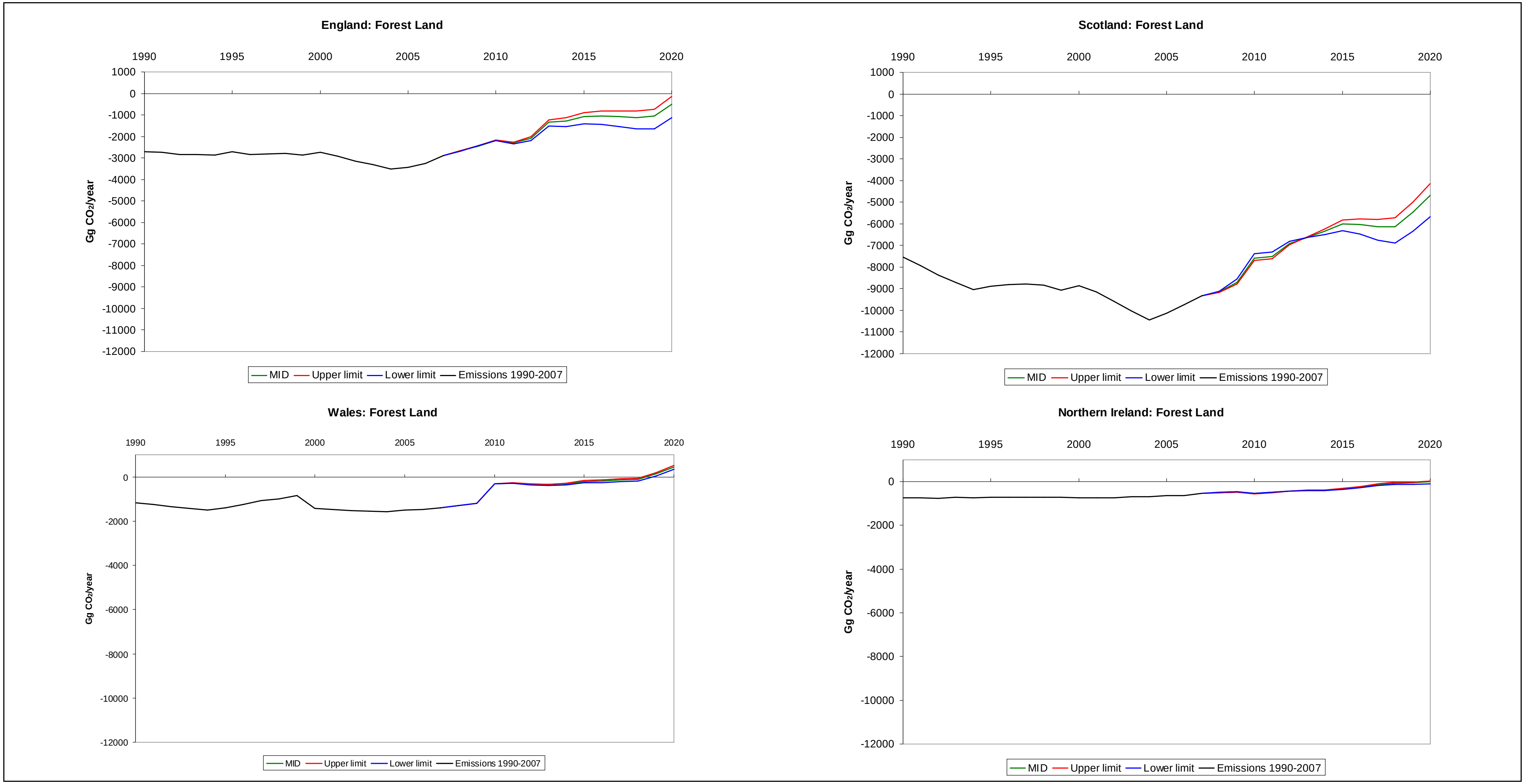

Figure 4-6: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Forest Land Category (5A) for 3 future emissions scenarios.

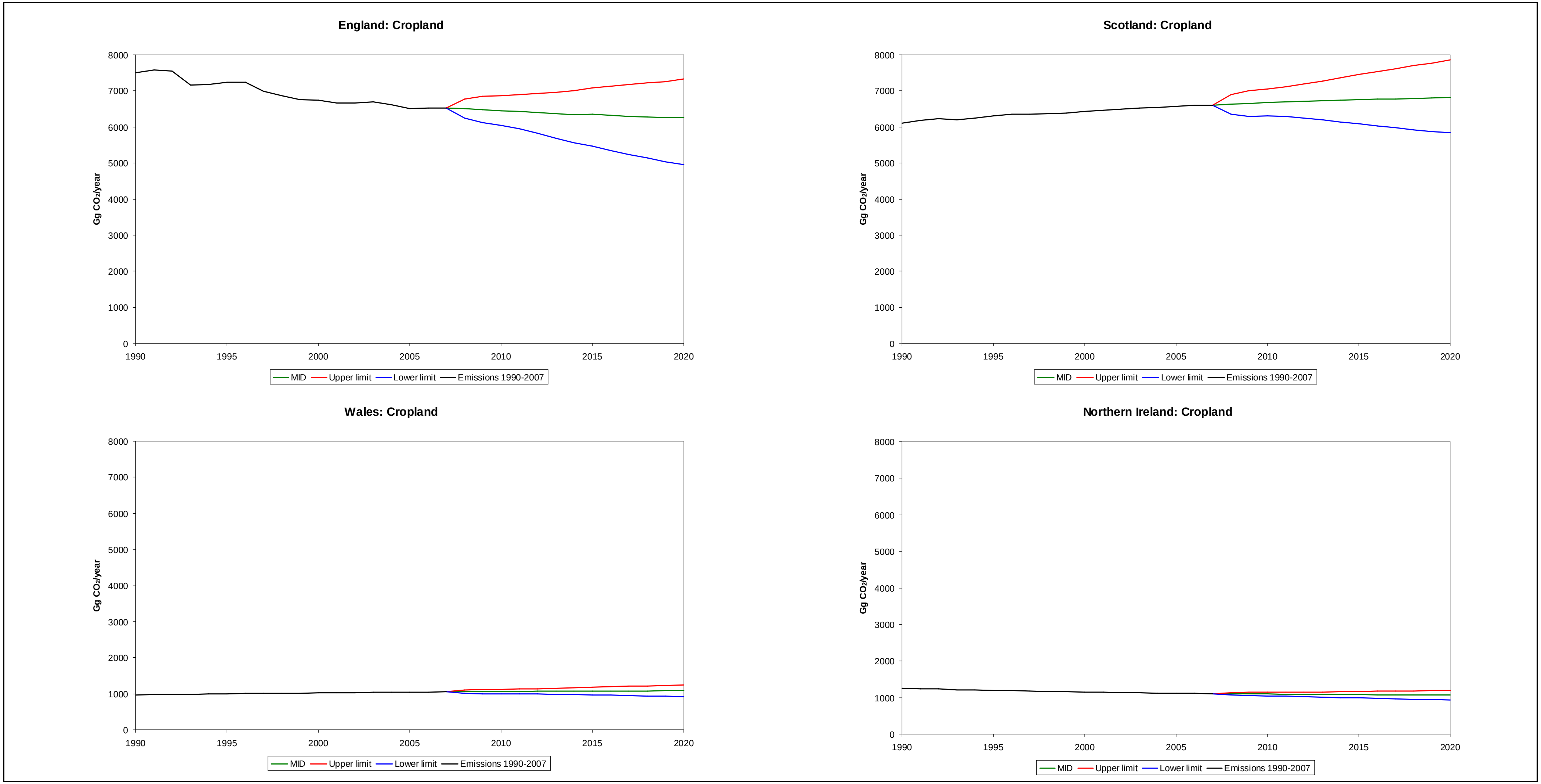

Figure 4-7: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Cropland Category (5B) for 3 future emissions scenarios

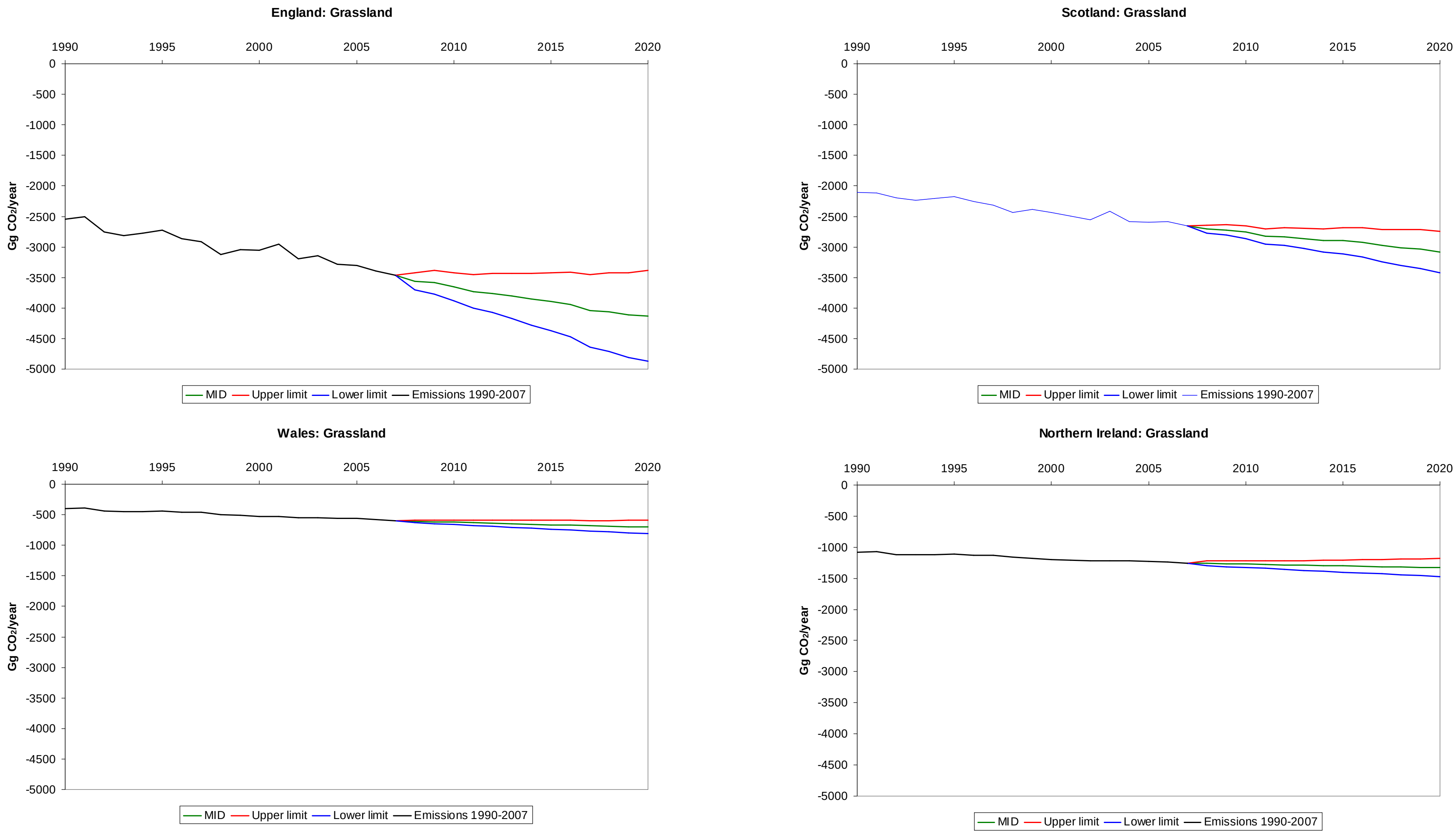

Figure 4-8: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Grassland Category (5C) for 3 future emissions scenarios

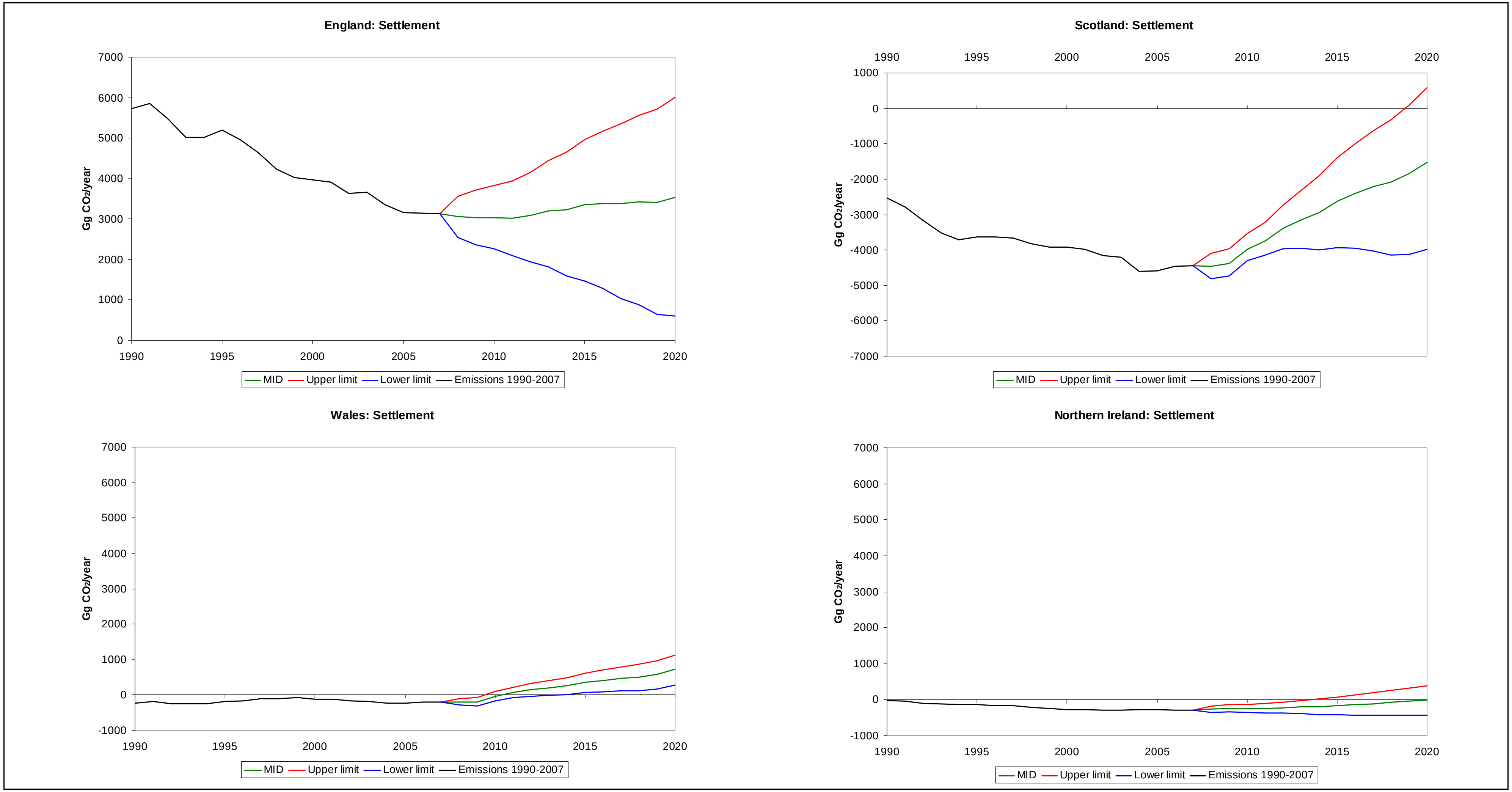

Figure 4-9: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Settlements (Urban) Category (5E) for 3 future emissions scenarios

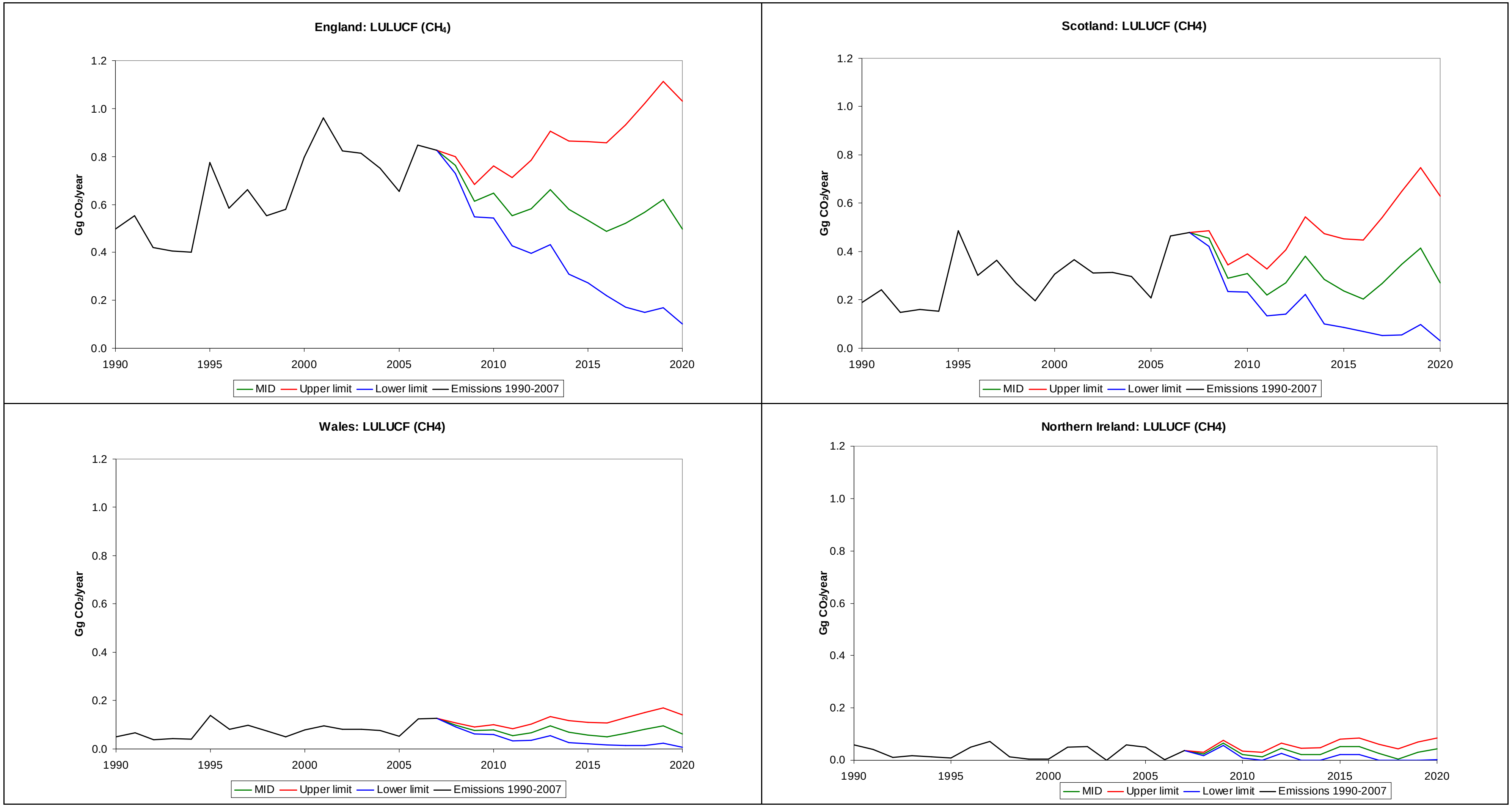

Figure 4-10: Projections to 2020 of total emissions of methane (CH_4) from the atmosphere in England, Scotland, Wales and Northern Ireland for 3 future emissions scenarios

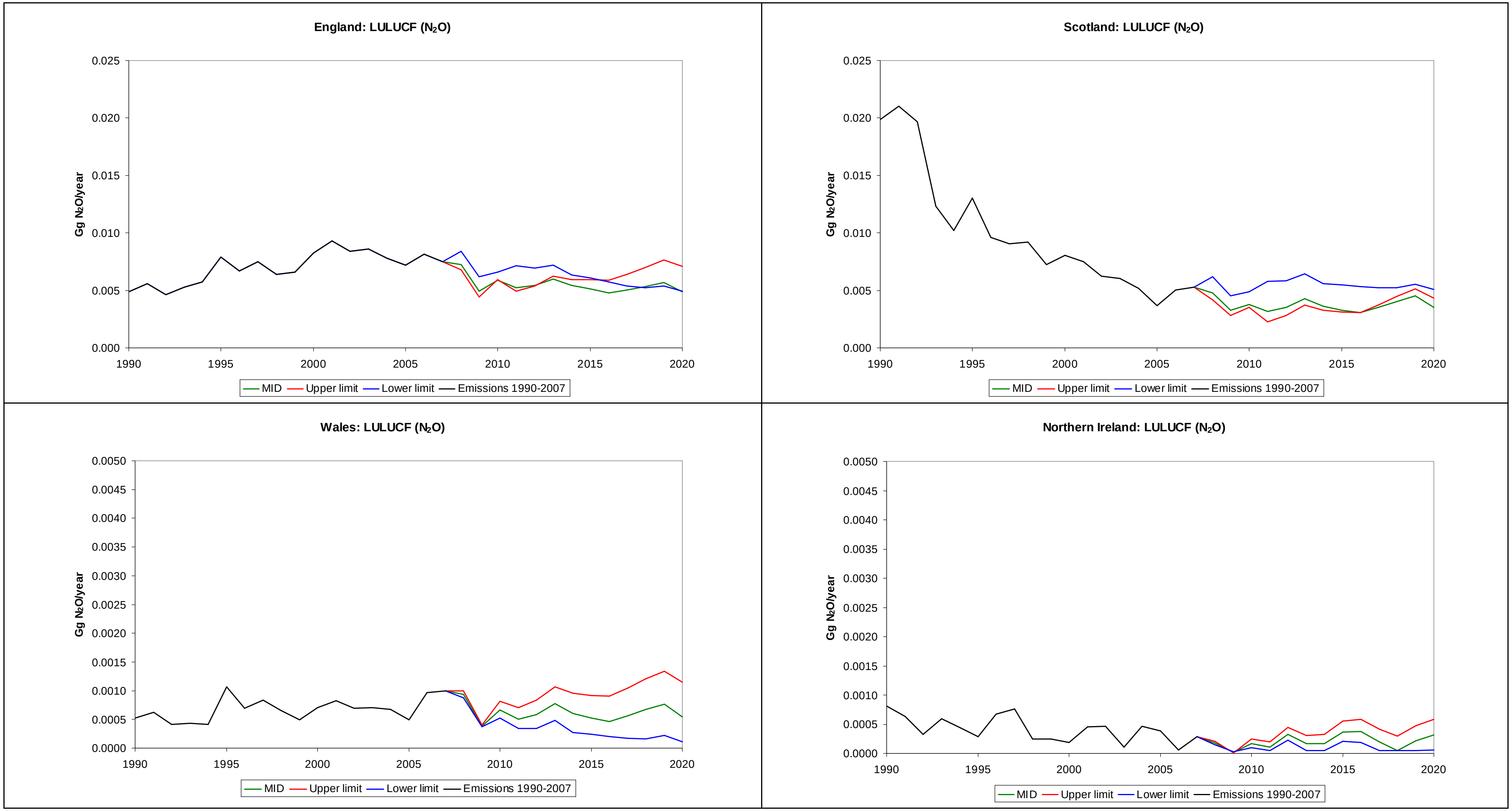

Figure 4-11: Projections to 2020 of total emissions of nitrous oxide (N2O) from the atmosphere in England, Scotland, Wales and Northern Ireland for 3 future emissions scenarios (note difference in scales)

5. Improved operational methods for inventory calculations (WP 2.1)

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Centre for Ecology & Hydrology, Bush Estate, Penicuik

Streamlining of the inventory production system has continued and there has been increased use of Matlab scripts to process and compile inventory data. The Matlab version of C-Flow was also used to produce the 5A inventory numbers for the first time this year.

We have continued to add information to the web-based ‘wiki’ inventory manual, which is intended for CEH internal use only at this stage. The wiki is proving to be a useful resource, containing documentation and workflow procedures (the technical details of inventory methods) and with new information immediately available to all colleagues.

The most significant recent development has been a successful bid for internal CEH funding (Science Budget) for ‘Greenhouse gas inventory database development’ starting in June 2008. The aim is to move the inventory data into a relational database in order to:

- simplify the annual updating process (adding the raw data)
- automate some of the calculations (remove the need for some of the spreadsheets)
- enable efficient version control
- generate an auditable workflow
- simplify the preparation of the required output formats
- enable more flexible interrogation of the data
- make it more transparent to current and any future staff.

The overall aim is to spend less time on the production and formatting of inventory numbers and more time on inventory development and science. We hope that the initial work on this will be completed by November 2008 in time for the production of the next inventory. The database development supersedes the proposed ‘report generator’ software.

Wider developments in information management in CEH (in which D. Mobbs is involved) are also likely to produce benefits to the inventory project over the coming year.

6. Incorporation of N_2O and CH_4 emissions and removals due to LULUCF (WP 2.2)

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Emissions of greenhouse gases other than CO_2 in the Land Use Change and Forestry Sector (in the latest CRF tables) come from 4 types of activities: (i) application of fertilisers to forests producing N_2O, (ii) emissions from drainage of soils and wetlands, (iii) N_2O emissions from disturbance with land use conversion to cropland, and (iv) biomass burning.

Emissions from N fertilisation of newly planted forests have now been included in the inventory (see Chapter 1 for details). There has been no progress in the estimation of emissions from drainage or land use conversion to cropland (see discussion in Chapter 6 of the 2007 Annual Report). This will be kept under review as more scientific information becomes available. The latest guidance/methodologies on the Agriculture, Forestry and Other Land Use sector in the IPCC 2006 Guidelines will also be examined and applied as appropriate. Emissions from biomass burning (from deforestation and wildfires) are reported in the inventory and described in Chapter 1; emissions from wildfires are included for the first time this year.

7. Methodology for incorporating effects of variability in forest characteristics (WP 2.3)

The Forest Land category (5A) is the largest net sink in the UK's LULUCF sector and flux estimates under Articles 3.3 and 3.4 of the Kyoto Protocol are also derived from this category. The LULUCF GHG inventory and projections for forest carbon stocks currently make a range of broad assumptions relating to species composition, productivity and forest management. The aim of this work package is to investigate these assumptions in more detail.

Under WP 2.3 (milestones II, VI and IX), predictions for the 2005, 2006, 2007 and 2008 forest production forecasts and implications for projections were reviewed and compared. As reported previously major changes were not expected and this has proved to be the case. The aim of this Work Package has been to fully understand the results of the 2005-2008 forecasts to permit a critical appraisal of revised forecasts, based on a radically updated approach, which have been scheduled for completion shortly after the end of this contract. The updated forecast approach is still being implemented as part of research and development not covered in this contract and an initial run of a revised forecast is now due for release in 2010, with progressive amendments in 2011-13. At this stage it has not been possible to assess the magnitude of possible changes to predictions of timber production and growing stock development.

Under WP2.3 (milestones V and VIII and XI), Forest Research extracted, processed and analysed data from the FC national inventory (NIWT I) carried out during the 1990s. This information was used to investigate spatial variation in the species composition and age class structure of woodlands across Great Britain. Data were summarised for grid squares with a resolution of 20 km x 20 km (the finest possible based on NIWT I) and the results were used to underpin the estimation of forest carbon stocks at this spatial scale. However, neither draft nor final versions of scenarios of forest management in the Devolved Administrations were fully prepared and reported, and the approach for representing the diversity of management across the UK forest estate remains unresolved.

Due to capacity constraints, Forest Research was also unable to respond to a later request (February 2009) for provision of example yield tables indicating the range of management practices currently relevant to UK forestry and the extent of departures from standard management assumptions. This was needed to enable completion of milestone XI. As a consequence, questions remain about how to best represent and model carbon stocks in relation to spatial variations in the growing stock of UK forests as well as systematic variations in approaches to forest management.

8. Further development of survey methods for Kyoto Protocol monitoring and verification of UK forest carbon stocks: The NFI protocol for measurement of growing stock (WP 2.4)

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8.1 Introduction

Progress has been achieved in the development of the methodology for a new National Forest Inventory (NFI, originally known as NIWT 2) for Great Britain, to be carried out by the Forestry Commission. Implementation is now proceeding with the aim of completing the first assessment cycle by 2014.

The field assessments for the NFI are directly relevant to the estimation carbon stocks in woodland, particularly in standing trees and deadwood. Currently there are no proposals for collection of data within the NFI relevant to estimation of soil carbon in woodlands.

The most substantial protocol in the NFI, which is concerned with assessment of growing stock in 1 hectare sample squares, is described in this report. The general approach has already been considered by Matthews and Mackie (2008) in their description of a *sample-based inventory* methodology. This approach is most suitable for the estimation of carbon stocks and stock changes in very large forest estates or expanses of woodland, typically consisting of collection of stands with a total area of many thousands or even millions of hectares, such as is the case for the UK forest estate.

8.2 Fundamentals of NFI survey and sampling approach

Currently, the proposed basic NFI sampling scheme involves (Figure 8-1):

- Digital mapping of all forest areas with an area of at least 0.5 hectare in advance of selection of sample areas. (This work is already taking place and is being achieved through interpretation of aerial photographs.)
- Superposition of 8 km x 8 km grid onto map. Identification of 1 hectare square in the southwest corner of each of these grid squares. If the 1 hectare square contains at least 0.05 ha of woodland, then the square is included as part of a systematic sample of forest areas. The adoption of this basic grid for sampling enables some consistency with other monitoring exercises, notably BioSoil (INBO, 2004).
- Identification of a further sample of 1 hectare squares containing woodland by random selection. (Squares containing partial areas of woodland are selected with less frequency than squares formed completely of woodland – rules are defined to determine these relative frequencies.)

The total number of 1 hectare sample squares is selected to achieve target levels of precision in the results for variables of interest at the appropriate national or regional scale. This will involve assessments in around 15,000 × 1 hectare sample squares.

The proposed NFI sampling scheme is an effective compromise between efficient statistical design and a requirement for flexibility in inventory objectives. The adoption of a primarily random sampling scheme for location of 1 hectare squares maies it possible to very easily enhance the basic level of sampling in particular areas of woodland in small regions or localities within the countries, in order to address the requirements of local stakeholders for more detailed or precise inventory information.

Survey approach in sample squares

The proposed survey approach in each 1 hectare sample square involves three elements (Figure 8-2):

- The area within the 1 hectare square is broken down into homogenous stands (also referred to as ‘sections’) and areas not containing woodland, with a minimum area of 0.05 ha. (In many situations, the square will consist of a single section of woodland.)
- Abbreviated, generally stand-level, qualitative assessments are made in each stand (section) within the square (for example to establish general characteristics such as general species composition and qualitative information such as ease of access to the woodland).
- Plot-based assessments are made in each stand (section) within the square.

The use of plot-based assessments in all sections is a change from the two-stage sampling/assessment approach described in Matthews and Mackie (2008) and reflects findings from a pilot survey which gave indications of the relative precisions of rapid assessments and plot-based assessments, as well as an estimate of the number of plots needed to achieve a target precision for assessment of a section.

The NFI mensuration protocol for assessment of growing stock

An aerial photo/map (likely GIS-based on a laptop) of the 1 ha NFI sample square which has been stratified/differentiated into provisional sections should be available on the laptop. It is assumed that, prior to carrying out mensuration assessments, the surveyor will 'walk through' the 1 ha sample square, in the process confirming the demarcation of sections. It is also assumed that the broad characteristics of each section will be assessed and recorded including, for example, tree species present within each section. The details of these procedures are not specified here.

The mensuration protocol involves plot-based assessments, usually in each section containing woodland. The definition of woodland is a cover of trees with a canopy of at least 20% of the area.

All surveying/ground-truthing of each section will be carried out prior to the plot-based assessments in that section. This includes a determination of the number of storeys.

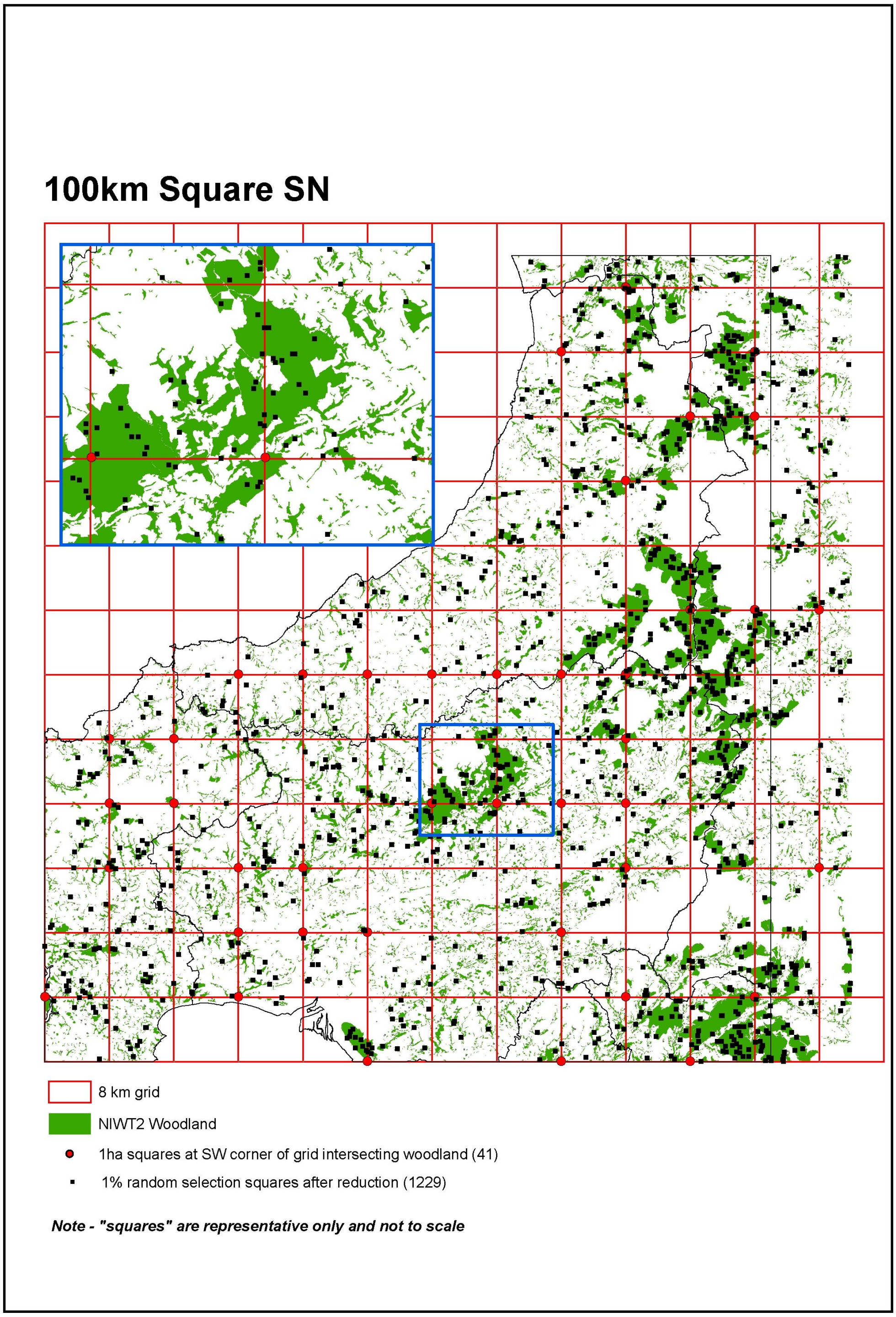


Figure 8-1. Proposed basic forest area sampling scheme for the Forestry Commission National Forest Inventory (NFI), illustrated for a 100 km x 100 km region covering North Wales. The forest area map is shown, as are the locations of 1 hectare sample squares coincident with 8 km x 8 km basic sampling grid. Also shown are randomly located 1 hectare sample squares representing approximately 1% of the forest area in the region.

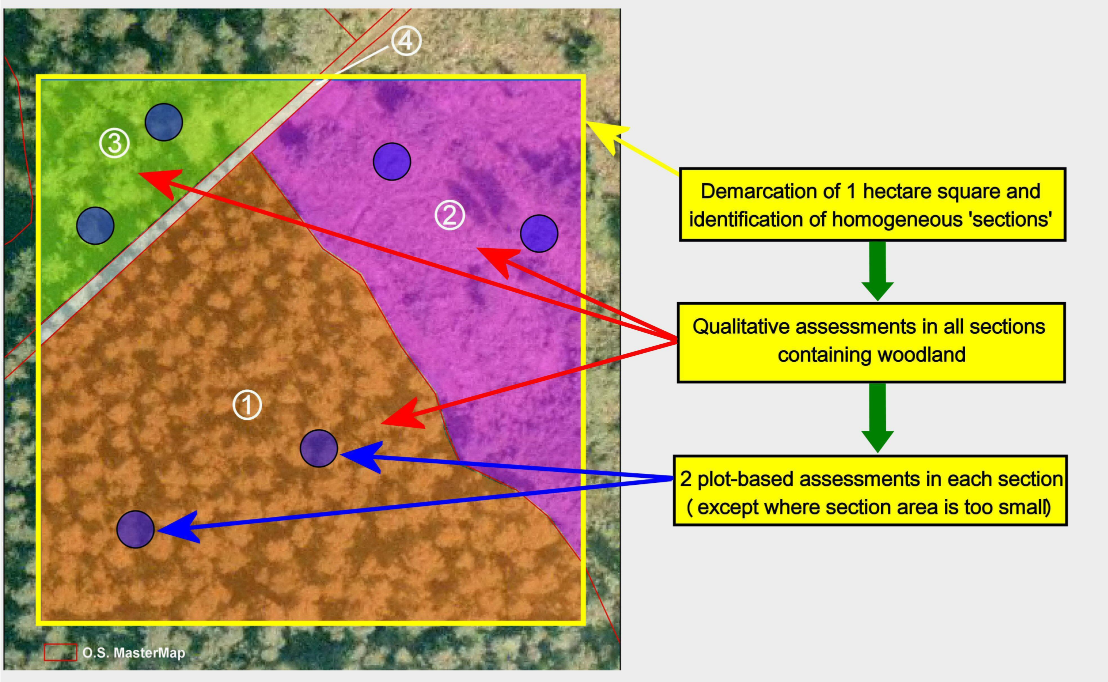


Figure 8-2. Illustration of proposed assessments in 1 hectare sample squares of the NFI inventory. The example square contains four ‘sections’ – three distinct stands and one distinct area not containing trees. Conventions are set for the minimum size of sections, including a minimum area of 0.05 hectare.

Determining of number of storeys in each section

A. The surveyor should pick up a sense of the number storeys in each section as they walk through the sample square.

B. The criteria to be used to determine what is a storey are given in Appendix 1, along with several examples.

C. The trees forming a storey must be 'measurable', defined here as the population of trees forming the storey having a mean dbh of at least 4 cm. The number of trees forming this population must represent at least 5% of the total number of measurable trees forming the section, as judged by visual assessment.

D. Record the number of storeys in the section. The tallest storey is assigned a code number of 1, the next tallest 2, and so on.

Note: As a basic convention the NFI survey defines strata at low heights relevant to the assessment of vegetation and regeneration. These are not considered as part of this protocol.

Plot-based assessments

All plot-based assessments will be carried out in each section of the sample square (subject to exceptional circumstances as described in Figure 8-3).

Normally, these assessments will involve laying out two circular 0.01 ha sample plots at non-overlapping, random locations in each section. The laptop will automatically select the locations of the two plot centres. However, in exceptional cases, assessments will be taken in either one plot or a single plot consisting of the entire area of the section. These exceptional cases occur when:

- It is not possible to accommodate two circular 0.01 ha plots within the section
- The surveyor judges that there are no more than 50 measurable trees in the section.

The decision tree in Figure 8-1 can be used to decide what type of plot-based assessment should be made.

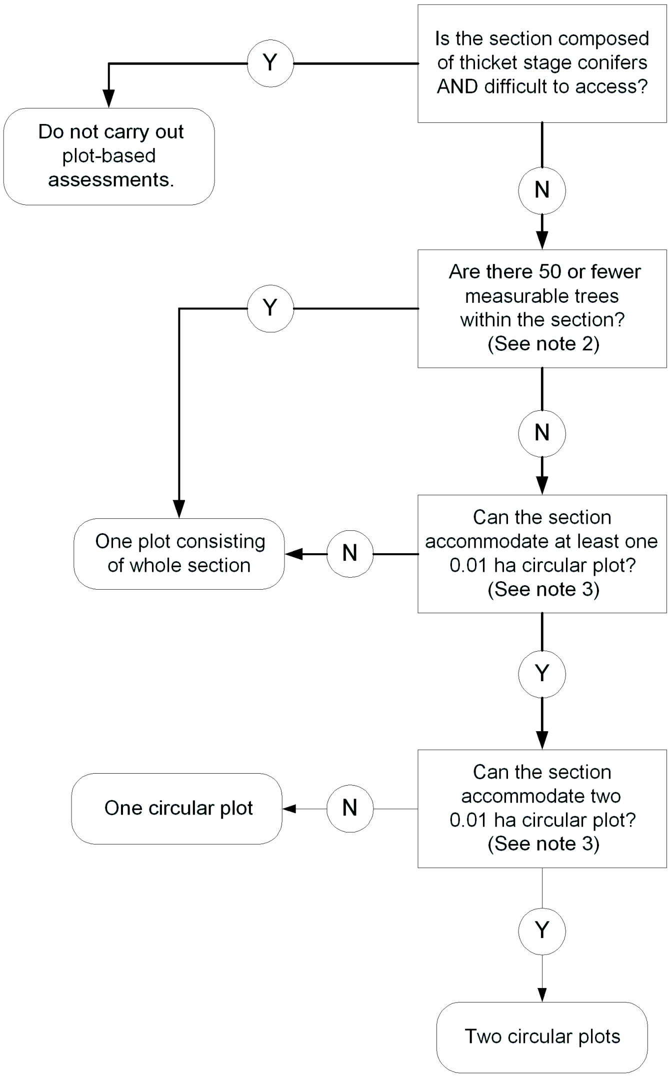


Figure 8-3. Decision tree for selecting plot-based assessment procedures (see accompanying notes).

Notes for Figure 8-3

1. For the purposes of plot-based assessments, a measurable tree is defined as being alive or dead and having a dbh of at least 4 cm.

2. Judging the number of measurable trees in the section will not always be easy. As a guide, Table 1 gives the average spacing between trees that would be expected if a section of given area contained 50 trees.

Table 8-1. Approximate average spacing between trees for sections of different area
equivalent to a total of 50 trees per section

Section area (ha)	**Average spacing between trees (m)**
0.1	4.5
0.2	6.5
0.3	7.5
0.4	9
0.5	10
0.6	11
0.7	12
0.8	12.5
0.9	13.5
1.0	14

3. A circular plot with area 0.01 ha will have a diameter of 11.2 m. The section will need to be able to accommodate at least one such plot.

Assessments taken at plot centres

At each plot centre, assessments are made of:

1. Total canopy occupancy in the section
2. Share of the canopy by species.

1. Total canopy occupancy in each section

a. A spherical densiometer is used for this assessment.

b. Stand at the centre of the plot. (The location of the plot centre(s) will be displayed on the sectioned map or digital image of the sample square on the laptop to aid placement.) The centre should be temporarily marked to allow the assessor to move around the section and return easily.

c. Ensure there are no branches from understorey trees directly above which may overestimate the canopy occupancy from the densiometer. Move position to the nearest unobscured location to the plot centre if this is the case.

d. Use a compass to point North and orient your body to face this direction. Count all of the unmasked dots on the face of the concave densiometer (indicated as blue stars in Figure 8-4) which are covered by a reflected image of the canopy. Record the count on the laptop.

e. Carry out the same assessment three more times facing East, South and West. Record the counts on the laptop.

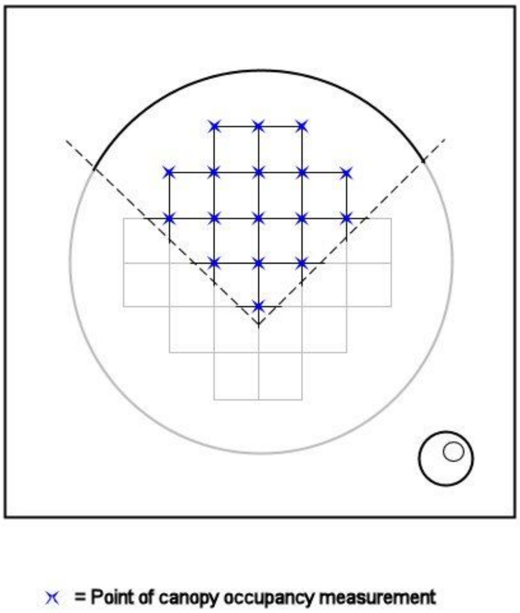


Figure 8-4. Spherical densiometer showing masking.

2. Share of canopy by species (%) in section

a. Standing at the centre of the plot, turn through 360º so that you can view all the trees surrounding you in the section and estimate the percentage contribution of each species *within the canopy of the uppermost storey only* to the total canopy to the nearest 10%. Record the percentages for each species in the appropriate field/cell on the laptop.

b. These assessments are subjective; examples of how such assessments may be made are given in Appendix 2.

c. If a species makes up less than 10% of the canopy it should be grouped according to the rules in the decision tree in Figure 8-5.

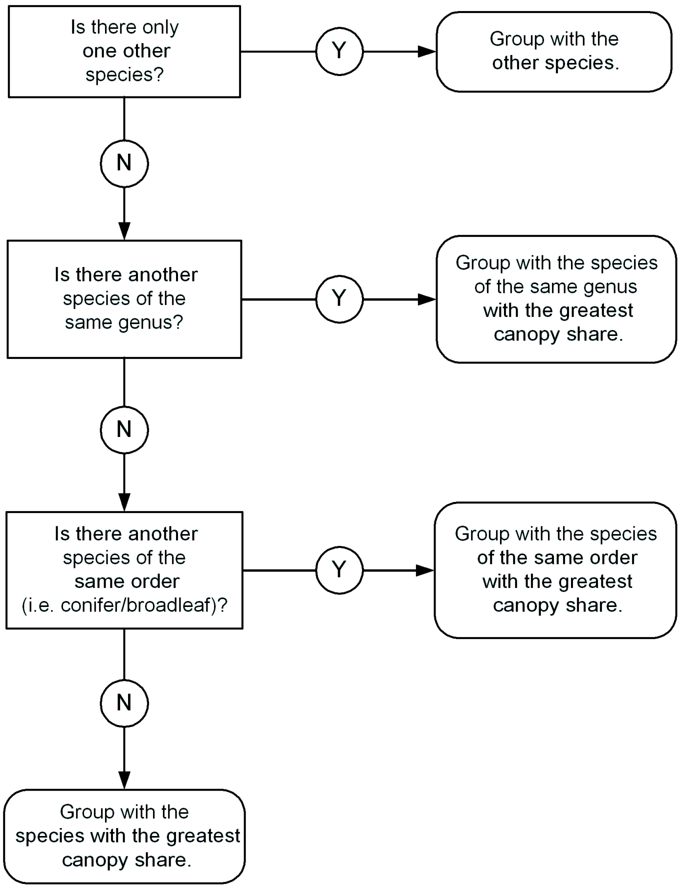


Figure 8-5. Decision tree for determining grouping of species by canopy share

Assessments in circular plots

In each plot:

a. All trees of height at least 1.3 m should be registered. Of these, trees with dbh less than 4 cm are counted but not assessed further. If a tree has a dbh of at least 4 cm then the dbh should also be measured and recorded. The stool of a coppice is defined as a tree, in this case the coppice is counted as one tree and stems are counted and recorded separately. A girthing tape to an accuracy of 1 cm diameter should be used to take these measurements. A small tree gauge is used for measuring dbh between 4 cm and 7 cm. The dbh values should be recorded along with:

   - The species of each tree
   - The status of each tree (dead or alive)
   - The storey within the section to which the tree most closely belongs (see section on determination of storeys).

b. Identify the tree of each species with largest dbh in the plot as a "dominant height sample tree". For each dominant height sample tree, identify the third nearest tree of the same species as a "stand height sample tree". Stand height sample trees may fall outside the sample plot. In the unlikely event that the section does not contain enough trees of the species then abandon the assessment of the stand height tree and make a comment to this effect.

c. Measure and record the dbh of each dominant height sample tree in the appropriate data field/cell on the laptop. Also measure and record its total height using a Vertex III/IV hypsometer. Place the Transponder on the tree(s) ensuring a good line of sight to the top of the tree when standing 1 to 1.5 times the height away from the tree.

d. Measure and record the dbh of each stand height sample tree. Also measure and record its total height using a Vertex III/IV hypsometer. Place the Transponder on the tree(s) ensuring a good line of sight to the top of the tree when standing 1 to 1.5 times the height away from the tree.

e. For each dominant and stand height sample tree (assessments c and d), measure and record the upper and lower crown heights and the crown diameter at two perpendicular points - at the widest point and at 90 degrees to this - (see Figures in Appendix 3 for guidance).

Assessments where the whole section is the plot

Within the section:

a. All trees of height at least 1.3 m should be registered. Of these, trees with dbh less than 4 cm are counted but not assessed further. If a tree has a dbh of at least 4 cm then the dbh should also be measured and recorded. The stool of a coppice is defined as a tree, in this case the coppice is counted as one tree and stems are counted and recorded separately. A girthing tape to an accuracy of 1 cm diameter should be used to take these measurements. A small tree gauge is used for measuring dbh between 4 cm and 7 cm. The dbh values should be recorded along with:

   - The species of each tree
   - The status of each tree (dead or alive)
   - The storey within the section to which the tree most closely belongs (see section on determination of storeys).

b. Randomly locate 3 sample points within the section. (This may be assigned automatically by the laptop.)

c. At each location select the closest tree of each species to the sample point; this tree is the first stand height sample tree. Select the third nearest tree of each species to the first tree; this is the second stand height sample tree. In the unlikely event that the section does not contain enough trees of the species then abandon this assessment and make a comment to this effect.

d. Measure and record the dbh of each stand height sample tree in the appropriate data field/cell on the laptop. Also measure and record its total height using a Vertex III/IV hypsometer. Place the Transponder on the tree(s) ensuring a good line of sight to the top of the tree when standing 1 to 1.5 times the height away from the tree.

e. For each stand height sample tree (assessments c and d), measure and record the upper and lower crown heights and the crown diameter at two perpendicular points - at the widest point and at 90 degrees to this - (see Figures in Appendix 3 for guidance).

8.3 Future developments

A full evaluation of the mensuration protocol, including a major pilot exercise, was carried out during 2008. Work is now proceeding to implement the protocol and begin work on NFI surveys. As data become available, the NFI will aim to provide the basis for:

- Direct estimation of the standing volume, biomass and carbon in GB forests
- Forecasting future development of carbon stocks in standing trees in GB forests through direct data links to a Forestry Commissions forecast system, currently at an advanced stage of development.

8.4 Acknowledgements

The authors wish to acknowledge the contributions of their colleagues in Forest Research and the Forestry Commission to the development of the ideas and content of this report. In particular the contributions of members of the NFI Statistical Methodology Working Group, Simon Gillam, Geoff Morgan, Ben Ditchburn, Lesley Halsall, Justin Gilbert, Peter Weston, Helen McKay, Mark Lawrence and Andrew Peace are gratefully acknowledged.

8.5 References

Matthews R.W. and Mackie E.D. (2008) Further Development of Survey Methods for Kyoto Protocol Monitoring and Verification of UK Forest Carbon Stocks. CEH contract science report June 2008.

INBO (2004) Background information concerning the BioSoil project. Research Instititute for Nature and Forest (INBO): Brussels. (http://www.inbo.be/docupload/2045.pdf).

8.6 Appendix 1. Determining storeys within a section

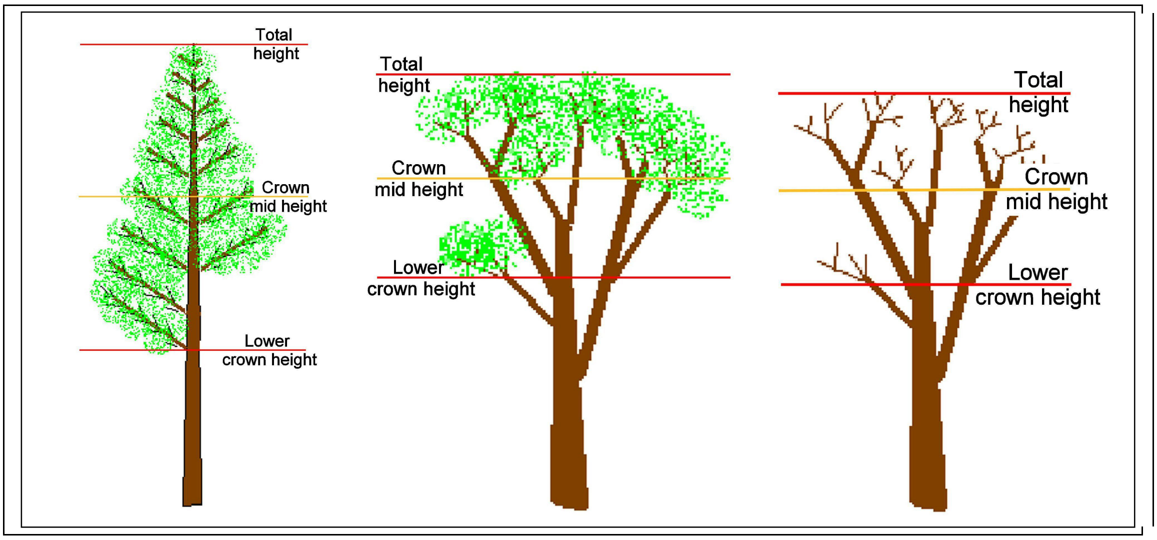
In assessing stand structure within a section for the presence of distinct storeys, it will often be the case that there is some variation in the heights of the trees but that it is difficult to determine from a simple visual assessment whether the trees of various sizes naturally group into different canopies and therefore into distinct identifiable storeys.

This appendix describes a procedure for the assessment of a section which will help in the decision about whether different storeys are present in the stand and, if such separate storeys can be identified, the means of identifying the members of a storey. Due to the complexity of stand structure in many situations, there is still likely to be a certain amount of subjectivity and dependence on the skill of surveyors in the identification of storeys within a section. Following the procedures described here will help to ensure some degree of consistency in the definition of storeys across stands of differing structures and across surveyors.

Before attempting to group trees into separate storeys according to their general vertical stature, it is first necessary to identify a definitive concept of the height of any particular tree for this purpose. Ultimately, a storey is defined by the similarity of the vertical positioning of the canopies of the trees belonging to that storey, and since tree canopies can vary considerably in general shape and form, the overall height of a tree will not always be the best representation of its vertical 'presence'. A better representation of the general vertical positioning in the canopy of a tree would be the mid-point between the bottom and top of the crown, which is here named the 'mid-crown' height.

The mid-crown height is then defined as the midway point between the lower crown height and the total height of the tree. The following diagrams illustrate three examples of the positioning of the lower crown, total and mid-crown heights of conifer and broadleaf species.

This is a formal definition of the mid-crown height. In practice it represents the height which is 'half way up' the crown of a tree.



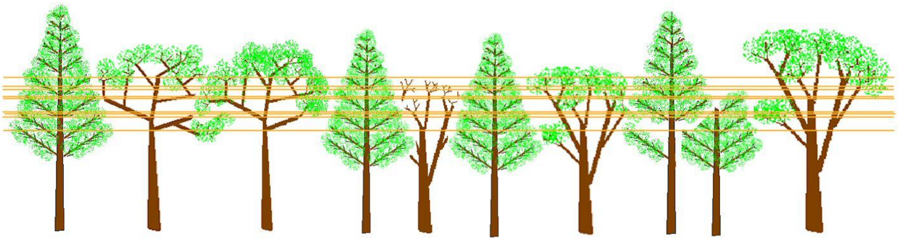
In first deciding whether an identifiable multi-storey structure exists within a section, consideration is given to the vertical distribution of the mid-crown heights of trees within the section. The essential question to ask is whether these mid-crown heights cluster into two or more groups on the vertical scale?

The convention to be used in answering this question is to visualize the mid-crown heights of the trees within the section and to decide, in the first instance, whether an upper storey exists in the section. This is the case if there is a distinguishable cluster of mid-crown heights in which the lowest member of that group is at least 4 metres higher than most of the rest of the trees within the section. This is described as ‘most’ rather than ‘all’ because there are likely to be situations in which there is a well-defined highest group and one or more lower groups but also an occasional tree whose height is spanning the vertical ‘gap’ between the highest group and the others. As a guideline, the tallest group can be identified as a distinct storey (the upper storey) if the number of trees that have mid-crown heights that are less than 4 metres lower than this tallest grouping do not represent more than 5% of the number of trees in the tallest group.

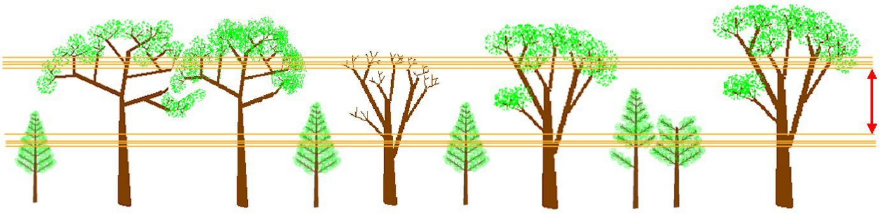
If these conditions exist in the section, the stand within the section can be considered to be a multi-storey stand and the trees in the identified tallest group (on the basis of mid-crown heights) form a stratum of the section which will be separately assessed and sampled. Any occasional trees that are less than 4 metres lower than the lowest in this tallest grouping are assigned to the lower strata. In turn, the mid-crown heights of the remainder of the trees in the section are also assessed for a clustering pattern and if a distinguishable second tallest grouping can be identified on the same basis (with mid-crown heights at least 4 metres higher than most of the remainder of the trees) then this second tier also forms a separate storey which will be treated as a separate stratum of the stand. The remainder of the trees of measurable height, including any which are less than 4 metres lower than the identified second tallest grouping, then belong to a third stratum of the stand. (In theory, there is no limit to the number of distinct storeys that could be identified in this manner, but in practice it is unlikely that stands with more than three distinguishable storeys will be encountered. Any woodland section may therefore be sub-divided into one, two or three separate storeys on the basis of canopy heights).

If it is not possible to identify a distinct upper storey using the guidelines described above, the height distribution of the trees within the section is too complex to be described as having a multi-storey structure. In these situations, in common with stands of a simple structure with a single storey of nearly uniform height, the section is regarded as possessing a single storey and is assessed and sampled accordingly.

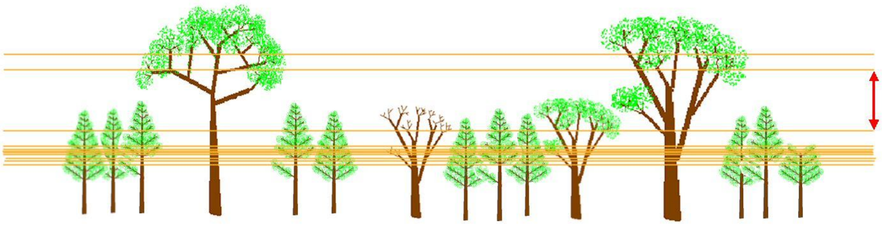
The following diagrams give a visual representation of different examples of stands which would be identified as multi-storey and those which would not, and would consequently be treated as single storey stands.



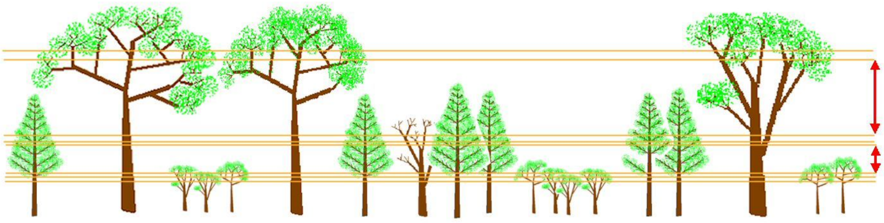
In this example it can be seen that the projected mid-crown heights of the trees form an obvious band. The stand has a single-storey.



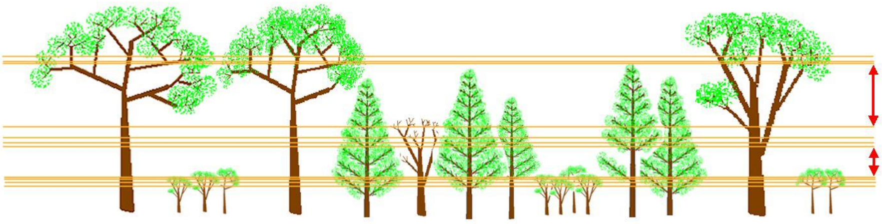
The projected mid-crown heights of the trees in this example fall into two bands with a clear gap between the two bands, greater than 4 metres (vertical arrow). The stand has a distinct upper storey and lower storey. A section containing such a stand would possess two storeys.



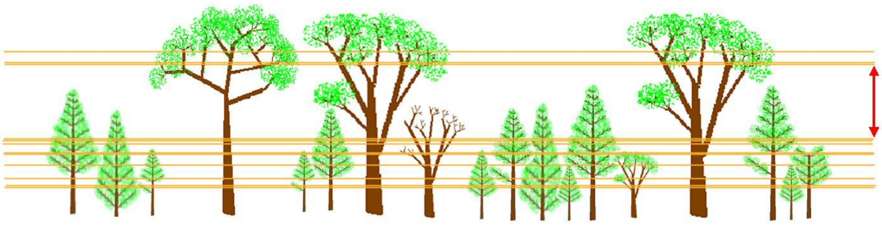
This example also shows two bands of projected crown mid-heights, although in this instance the members of the upper storey are widely spaced and therefore sparse. This storey is still treated as a separate storey.



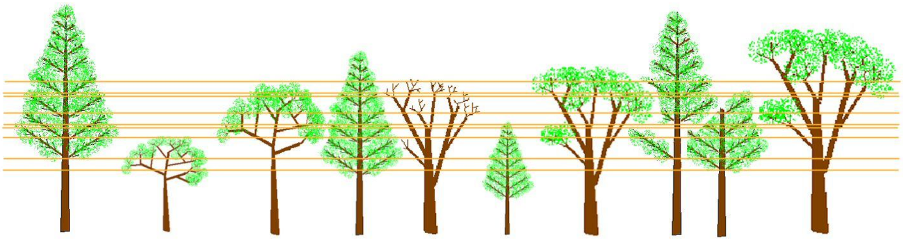
The projected mid-crown heights of the trees in this example fall into three bands with clear gaps between each of the bands, greater than 4 metres (vertical arrows). The stand has three distinct storeys - upper, middle and lower.



In this example, there are conifer trees with total heights similar to the upper storey. However, the trees have long crowns and by looking at the projected mid-crown heights it is clear that these trees belong to a lower storey (vertical arrows). This is another example of a three-storey stand.



The heights of the trees in this example are variable, but there is still a distinct upper storey. The band for the lower storey is wide, reflecting the complex structure, but there is a clear gap of greater than 4 m between the projected mid-crown heights for these trees and those forming the upper storey (vertical arrow). A section with a stand of this structure would therefore contain two storeys.



In this example the heights of the trees are very variable, reflecting a complex stand structure. It is not possible to distinguish obvious storeys (i.e. no bands in the projected mid-crown heights of trees). The test for a difference in mid-crown height of 4 metres is based on groups of trees forming distinct bands, not individual trees. A section containing such a stand would therefore be considered to possess a single (complex) storey.

It should be noted that storeys within a section may have very different lateral distributions. Some may be uniformly spread over the whole area of the section while others may occur in patches and do not cover the whole area of the section. Where such patterns give rise to separately identifiable areas of sufficient size during the mapping stage of the sample square, these may be accommodated in the partitioning of the sample square into separately identified sections. This will often not be the case, however, and it is expected that individual storeys within a section may often occupy only parts of a section, or vary greatly in density in different areas of the section. It may sometimes be found that sample plots laid out in a section will capture little or no trees belonging to a particular storey being assessed, while others capture a dense part of the storey. This is to be expected, dependent upon the structure of the stand within a section, and adjustment or rejection of a sampling point should not be made on this basis.

8.7 Appendix 2. Examples of estimating share of canopy by species. Amended excerpt from FR SOP 0242 draft (May 2008).

If the surveyor has decided that a section consists of one element, the share of canopy for that element is 100%.

If the surveyor has determined that a section consists of two elements, the total share of canopy for both elements will be 100%. For example, in a section consisting of an intimate mixture of Scots pine and European larch, where nine pine trees survive for every one larch tree and the crowns of both species appear to be of a similar size. The share of canopy for the Scots pine would be recorded as 90%, whilst that of the European larch would be 10%.

Details of calculations:

	Scots pine	European larch
Relative numbers of trees	9	1
Relative crown size	1	1

Canopy share for Scots pine = $\frac{(9 \times 1)}{((9 \times 1) + (1 \times 1))} \times 100$ = 90%.

Canopy share for European larch = 100% - 90% = 10%.

If the section described in example 2 also has one further element of a scattered Sitka spruce understorey, the share of canopy for the Scots pine and European larch would remain the same whilst the canopy share for the Sitka spruce would be recorded as 100%. The scattered nature of the understorey would be reflected in the results derived from other mensurational assessments.

If the surveyor has determined that a section consists of two elements - a sparse overstorey of Douglas fir standards and a dense, well developed understorey of western red cedar - then the canopy share for the Douglas fir would be recorded as 100%, whilst the canopy share for the western red cedar would also be recorded as 100%. The sparse nature of the overstorey would be reflected in the results derived from other mensurational assessments.

If the surveyor has determined that a section consists of three elements - a sparse overstorey of Douglas fir standards and a dense, well developed understorey formed of an intimate mixture of western red cedar and western hemlock - the canopy share of Douglas fir would be recorded as 100%. For the understorey, if two cedar trees survive for every one hemlock tree, and the projected crown areas of the cedar trees are about twice that of the hemlock trees then the share of canopy for the western red cedar would be recorded as 80%, whilst that of the western hemlock would be 20%.

Details of calculations:

	Western red cedar	Western
Relative numbers of trees	2	1
Relative crown size	2	1

Canopy share for western red cedar = $\frac{(2 \times 1)}{((2 \times 2) + (1 \times 1))} \times 100$ = 80%.

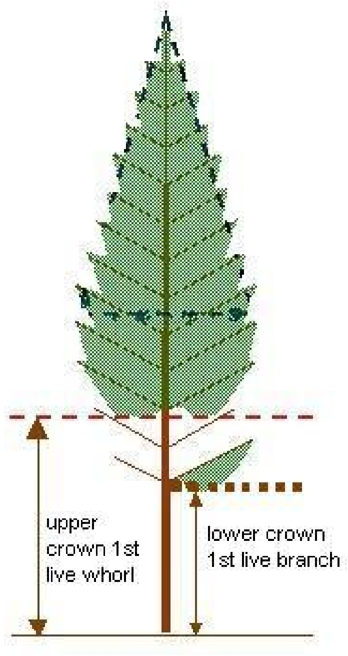
Canopy share for western hemlock = 100% - 80% = 20%.

Note: a simple calculator will be provided as part of the Toughbook software to assist with these assessments.

8.8 *Appendix 3. Crown and storey definitions. Including excerpt from FR SOP 0232 (May 2008).*

Lower Crown Height The height of **the lowest live branch** on the main stem (excluding epicormics and forks), recorded to the nearest 0.1 m. on hardwoods this is the lowest level of fine branching.

Upper Crown Height. The height on the main stem where the **lowest complete whorl** of branches occurs, recorded to the nearest 0.1 m.



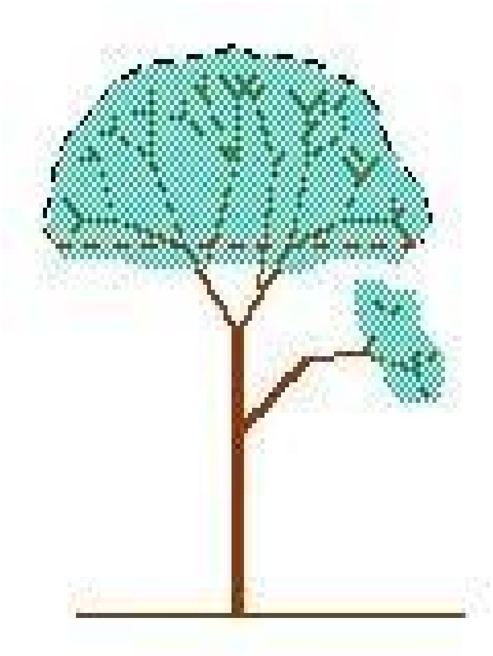
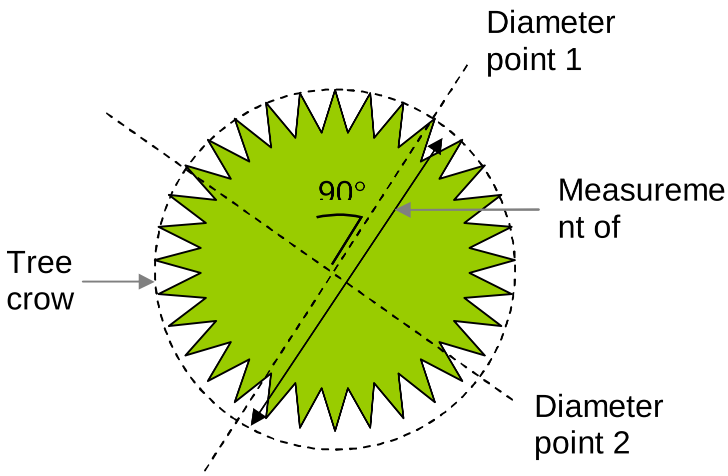


Diagram of tree crown diameter projection measurement

PLAN VIEW



9. Quantifying the effect of afforestation on soil carbon (WP 2.5)

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Centre of Ecology and Hydrology, Bush Estate, Penicuik, Edinburgh

9.1 Introduction

The flux associated with afforestation is the largest component of the LULUCF inventory. However, whilst the growth of above-ground biomass is relatively well quantified, the effect of afforestation on soil carbon is much less clear, and there are few pertinent data available. Previous work within LULUCF contracts has been directed towards the effect of planting conifers on upland sites and organic soils. In broad terms, peaty soils are thought to lose carbon, at least initially, whilst mineral soils are expected to gain carbon. Current estimates of the impact of afforestation come almost entirely from a single paper on conifers on organic soils (Hargreaves, Milne & Cannell 2003). With recent trends in UK forestry, there is a particular need to quantify the effect of planting broadleaved trees on ex-agricultural mineral soils. Here we aimed to measure this effect, using measurements at a site where tree plantations of different ages exist, and unplanted areas are available within the same locality to infer the soil carbon stock before planting.

9.2 Field Site and Methods

We used a site at Glencorse (55° 51’14” N, 3° 12’55” W), near CEH Edinburgh (Figure 9-1), where agricultural land had been planted with trees for use as seed nurseries and genetics trials around 1980. This provided stands of different species with known planting dates, as well as an unplanted control area (left as unmanaged grassland), and a comparison with the rest of the field which had remained in agricultural use since 1980 (variously used for arable and grassland (both cut for hay and grazed. The soil was classified as belonging to the Darvel series, a freely-drained brown earth derived from Carboniferous sediments.

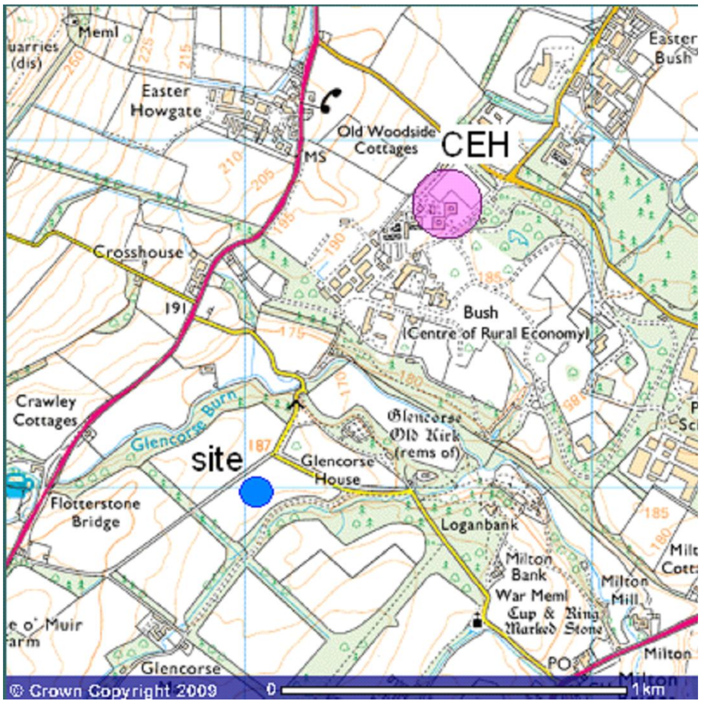

Figure 9-1. Location of Glencorse field site near CEH Edinburgh on Bush Estate.

Soil samples were taken along transects such that the effects of spatial location (mainly slope) could be accounted for in the statistical analysis (Figure 9-2). Two samples where taken at ten points within each treatment (the afforested, control, and agricultural areas).

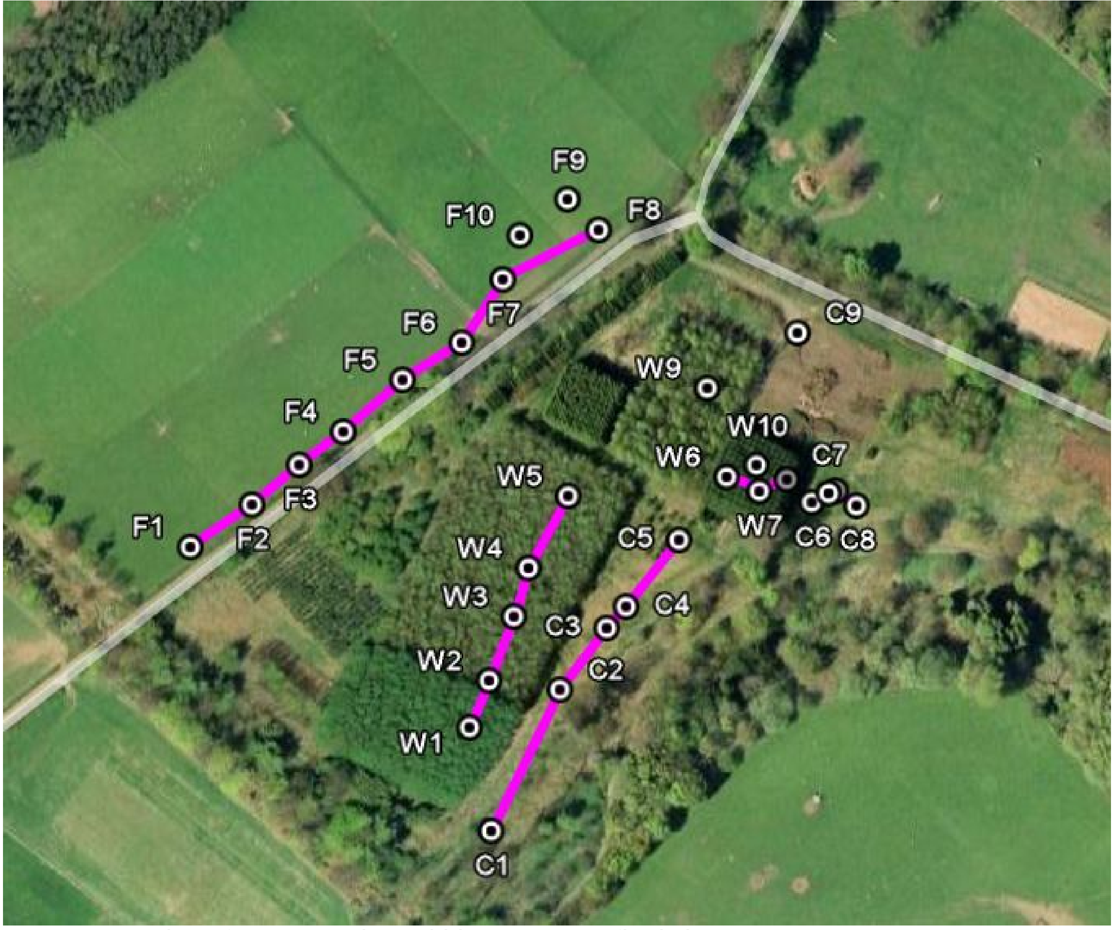

Figure 9-2. Location of sample points within Glencorse field site.

Samples were taken from stands of Sitka spruce, birch, and red alder. Each sample was a soil core, 60 mm in diameter and extending down the whole soil profile to the mineral layer. This was extracted using a 600-mm long soil corer (Giddings Machine Company, CO, USA), manually driven in with a slide hammer. Cores were extracted in an inner plastic sleeve, which was split into five 120 mm sections, so that each depth layer could be analysed separately. After the roots and stones had been removed using a 2-mm sieve, soil carbon content was measured using the loss on ignition (LOI) technique: a 5-g subsample of soil was weighed before and after being combusted in a muffle furnace at 500 ^{o}C for 120 minutes. A further subsample from each sub-section was analysed for carbon content using an Elemental Analyser at CEH Lancaster. Linear regression between the two was used to relate the percentage LOI values to percentage carbon content (Figure 9-3), and gave the best-fit equation:

$$C = -0.766 + LOI * 0.534$$

This carbon content value was applied to the mass of soil in each sub-section, and summed over the core to give soil carbon stock in kg C m^{-2}. These data were analysed by one-way ANOVA, with spatial location as a blocking term.

9.3 Results

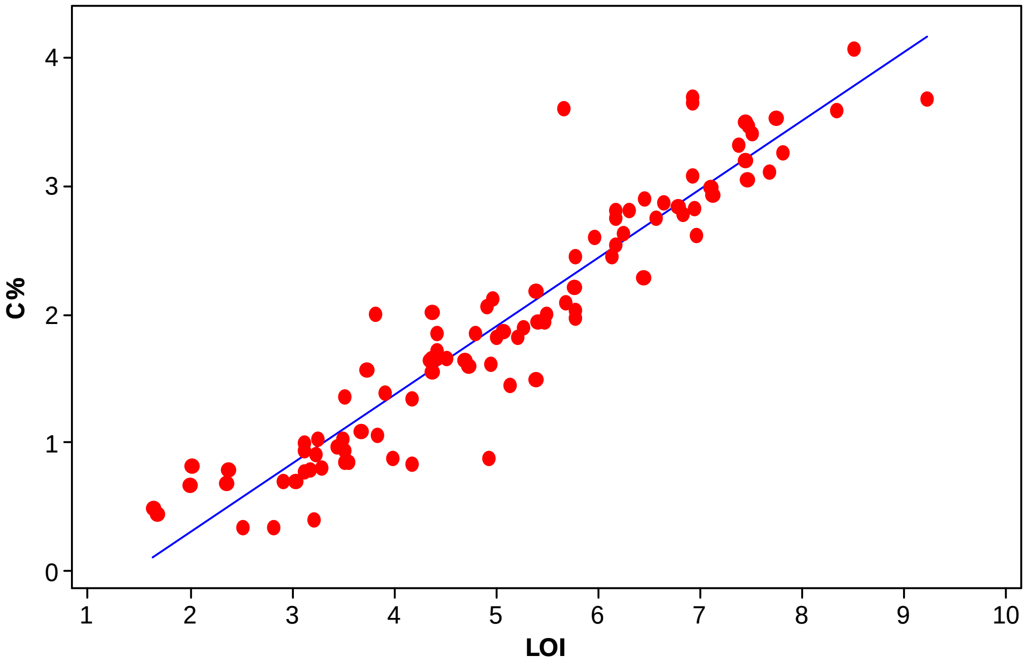

Figure 9-3. Relationship between loss on ignition and carbon content as measured by Elemental Analysis.

Table 9-1. Analysis of variance table showing the contribution of the three land use treatments and spatial location to the variance in soil carbon (kg C m^{-2})

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Spatial location	7	59.598	8.514	4.07	
Treatment	2	153.117	76.559	36.60	<.001
Residual	38	79.479	2.092		
Total				47	292.195

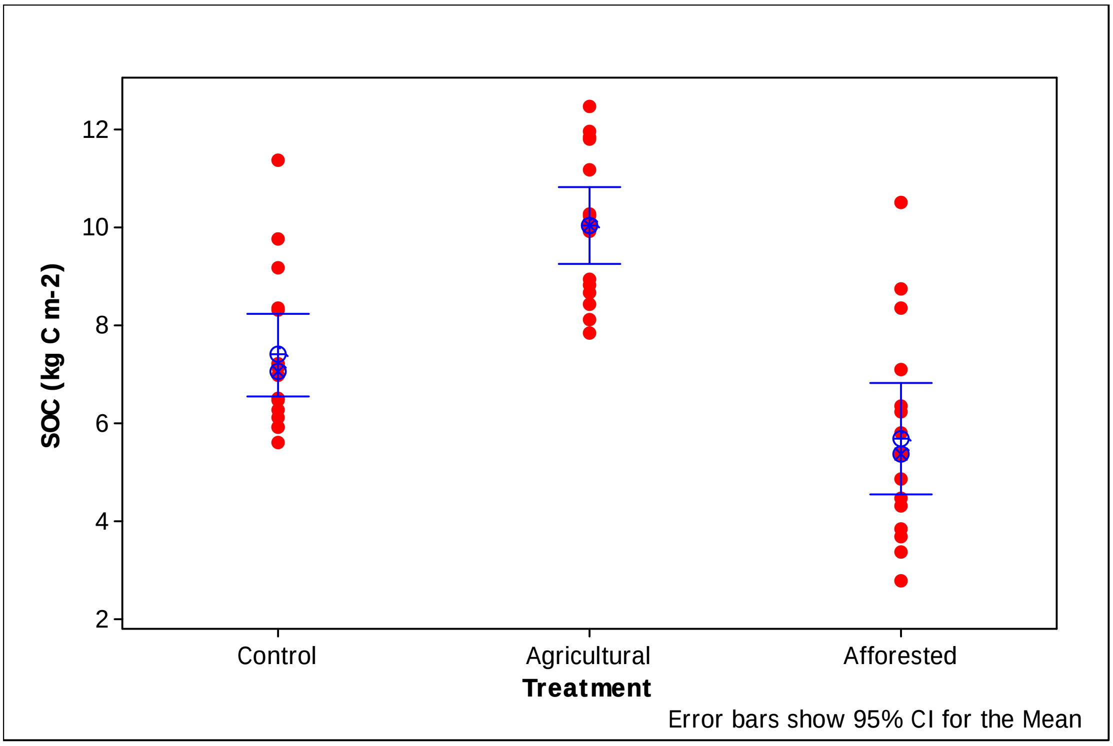

Figure 9-4. Plot showing the soil carbon stock for each core by land use treatment.

Significant differences were found between the treatments ($p < 0.001$, Table 1) with the afforested treatment having the lowest soil carbon stock ($\bar{x} = 5.7$ kg C m^{-2}), followed by the unplanted control ($\bar{x} = 7.4$ kg C m^{-2}), with the agricultural land holding the highest soil carbon stocks ($\bar{x} = 10.0$ kg C m^{-2})(Figure 9-4). Within the afforested area, little difference could be seen between the birch and Sitka spruce stands ($\bar{x}$ birch = 5.036 kg C m^{-2}, $\bar{x}$ ss = 5.276 kg C m^{-2}), and there were not enough cores with the red alder stands to make the comparison.

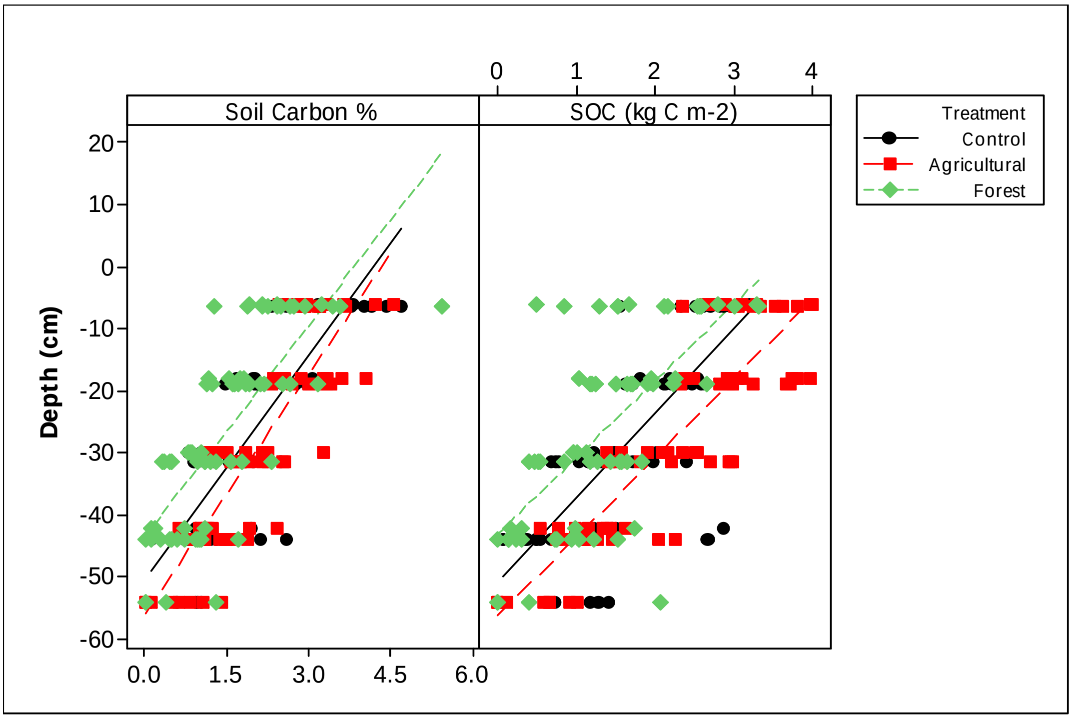

Figure 9-5. Scatter plot showing the change in soil carbon with depth by treatment.

9.4 Discussion

The implication of these results is that planting trees does not sequester as much carbon as we estimate in the LULUCF inventory. Currently, in the C-FLOW model, one third of the carbon sequestered resides in the soil. These data are at odds with this, and suggest the soil may actually be a loss term. The results are relatively clear-cut here, and the methods straightforward, so there is little doubt that the effects seen here are real. The main questions concerns how widely applicable these results are, and what mechanism has caused the differences. This is only one experiment at a single location and soil type, and a different result may be found elsewhere under different conditions. To understand whether the results may be more generally applicable, we need to understand the mechanism(s) by which afforested land has a lower soil carbon stock. This is difficult to discern from these results, but three possible mechanisms stand out. Firstly, disturbance of the soil during planting may have accelerated decomposition through breaking up soil aggregates and aerating the soil. Secondly, there may have been a greater litter input to the agricultural soil than to the forest soil. Depending on the management of the agricultural field, considerable quantities of organic matter may have been added over the last 28 years, in the form of animal manure and crop residues (mainly incorporation of straw). This is being examined further through management records at SAC, who manage the farm. A third possibility is a ‘priming’ of the pre-existing soil organic matter by root exudates or litter inputs, such that the organic matter decomposes quicker in the forest soil. This phenomenon is reasonably well documented, though poorly understood (Kuzyakov et al. 2000). The fact that the unplanted control had lower soil carbon than the agricultural field, suggests that soil disturbance was not the soil mechanism, and reduced litter is a plausible explanation. The fact that the afforested area had lower soil carbon than the unplanted control suggests that priming effect may have had a role. The weakness of our experimental design is that there are no data from before the land use change occurred, so we cannot rule out the possibility our results simply reflect differences in prior conditions.

Figure 9-5 shows that it is not simply an artefact of soil depth, and is more closely related to differences in carbon content than bulk density. The decrease in carbon content follows the trend seen by Bellamy & Rivas-Casado (WP2.8, this report) in the NSI data for first-rotation forest sites. When expressed as the absolute decrease in carbon content, our value (-0.25 g kg^{-1} y^{-1}) is an order of magnitude smaller than the NSI value (-2.38±0.53 g kg^{-1} y^{-1}). However, comparing the decrease in carbon content on a percent basis relative to the initial state (assumed equal to the agricultural treatment), we obtain a value of -1.1 % y^{-1}, more than double the NSI value (-0.44% y^{-1}). Two previous meta-analyses of the impact of afforestation on soil carbon shown both positive and negative effects, with no clear conclusion. Indeed, the two largest meta-analyses disagree with each other, with Post & Kwon (2002) finding a net increase and Guo & Gifford (2002) finding a 12-15% reduction in soil carbon.

The work is timely in relation to the current interest in biomass energy, and in quantifying the economic costs and benefits of different options for sequestering carbon and mitigating climate change. To do this, the environmental benefit of afforestation (in various forms) needs to be accurately known. Given the lack of data, the effects on soil carbon are highly uncertain, and further work is needed to address this. The impact of afforestation on soil carbon stocks could be measured using several possible approaches:

Long-term measurements of soil carbon before and after forest establishment at a range of sites. The Scottish Forestry Alliance manage nine sites in Scotland where recent planting has taken place, and baseline surveys of soil carbon were carried out prior to planting. A re-sampling of these sites could measure the change in soil carbon 8-10 years after planting. This is the work originally proposed work, and is particularly important in the light of these results, as there are very few experimental data available, and these provide a ready-made baseline.

Recent national-scale survey data from CEH Countryside Survey, Forest Research, and Macaulay (and NSRI Cranfield as reported by Bellamy & Rivas-Casado, WP2.8, this report) could be used to track how soil carbon has changed at forest sites between surveys. The existence of other pertinent data in Forest Research should be investigated, although all the recent work in the BioSoil project has focussed on estimating current stocks, not change following afforestation.

Direct Flux Measurement – A complementary measurement approach is to measure fluxes directly by eddy covariance. Forestry Commission Scotland is establishing a number of farms for demonstrating the potential of short-rotation forestry. One or more of these could be instrumented with the necessary equipment to monitor the carbon balance over the transition from agriculture to short-rotation forestry.

9.5 References

Bellamy, P. and Rivas-Casado, M. (2009) Work package 2.8: Statistical analysis of NSI soil carbon changes in relation to climate and land management changes. This report.

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Francis Group.

Guo, L., B. & Gifford, R., M. (2002) Soil carbon stocks and land use change: a meta analysis. Global Change Biology 8, 345-360.

Kuzyakov, Y., Friedel, J.K., & Stahr, K. (2000) Review of mechanisms and quantification of priming effects. Soil Biology and Biochemistry, 32, 1485-1498.

Post, W., M. & Kwon, K., C. (2000) Soil carbon sequestration and land-use change: processes and potential. Global Change Biology 6, 317-327.

10. Assessment of carbon fluxes in ploughed upland grasslands: a plot-scale experiment to detect the effect of cultivation on soil organic carbon (WP 2.6)

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June 2008

10.1 Introduction

The UK LUCF Carbon Emission Inventory requires information on the fluxes arising in the transition between different land uses (Milne 2003). 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. 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 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 very few experimental data from the UK. Here, we describe a plot-scale experiment to detect the effect of cultivation on soil organic carbon content. The site had never previously been disturbed, and the experiment attempts to represent the transition from semi-natural vegetation to improved grassland, emissions from which form a large component of the present-day LULUCF inventory. To elucidate the effect of cultivation *per se*, we compare cultivated and uncultivated plots which were maintained free from vegetation with herbicide, so that variations in regrowth of vegetation, and consequent litter input, were not an influence. Recent work (Smith and Conen 2004) suggests that the increase in N_2O emissions in “no-till” agriculture may outweigh the effect of carbon sequestration, in terms of Global Warming Potential (GWP). Therefore, we include measurements of N_2O and CH_4 emission in this study, to obtain a more complete picture of the effect of cultivation on the greenhouse gas balance.

10.2 Methods

Field site and treatment

The experimental site chosen was on House O’ Muir Farm near CEH Edinburgh (Figure 10-1), which is managed by the Scottish Agricultural College. The site is at an altitude of 290 m in an area which is used for rough grazing at a very low stocking density, but has received no improvement or cultivation. Nearby fields have been improved, and though the experimental site is similar, it is surrounded by steep slopes where improvement or cultivation using farm machinery would be impractical. The soil is a relatively shallow (10-20 cm) brown earth of the Sourhope series, but reasonably high in organic matter (10 % carbon content).

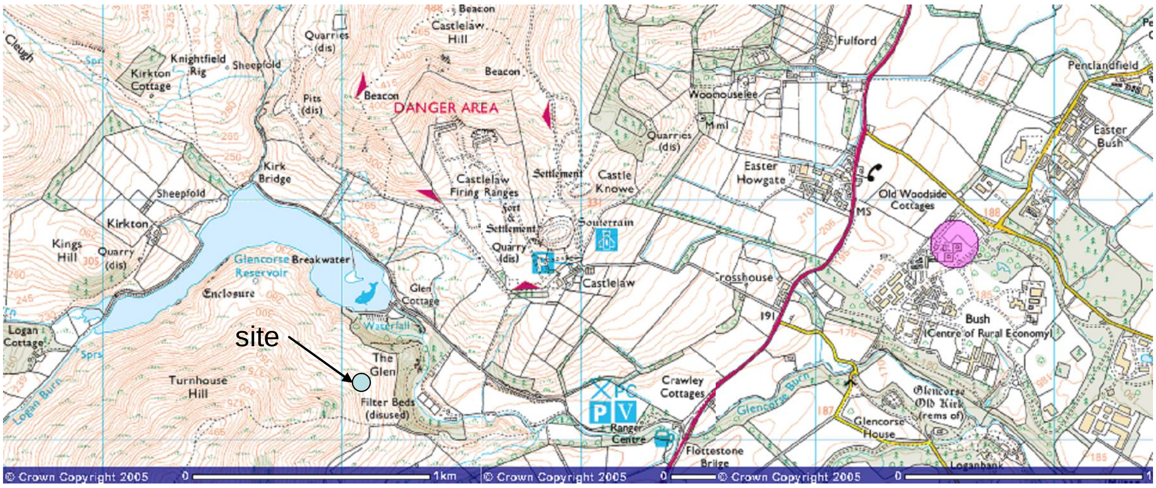
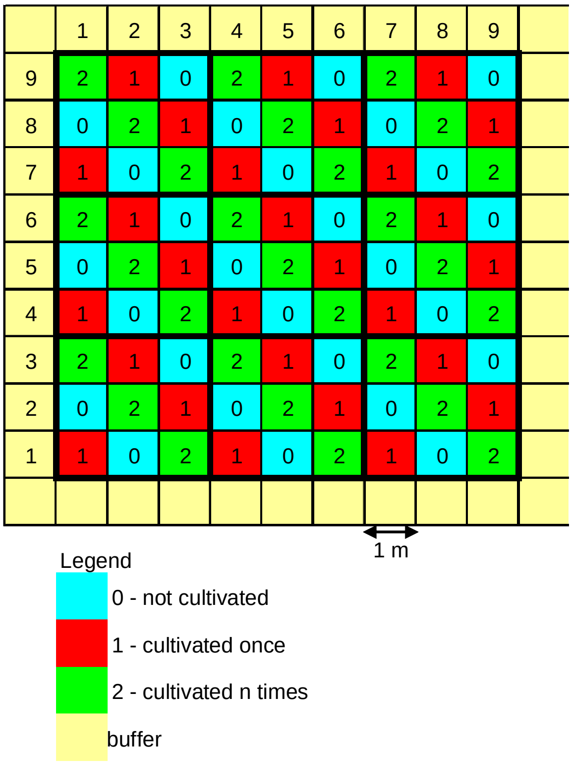


Figure 10-1. Location map of experimental site at House O' Muir Farm.

In June 2005, an 11 x 11 m area was fenced to exclude sheep. The vegetation within was cut to a height of 10 cm using a strimmer and the litter removed from the experimental area. Glyphosate herbicide ('Roundup') was applied on 8 July, with a further treatment on 14 July. This killed the remaining vegetation over a number of weeks, and the litter was removed by strimming and raking in August. Within the fenced area, the outermost 1 m was reserved as a buffer zone to reduce edge effects from surrounding vegetation. The inner 9 x 9 m was divided into 1 x 1 m plots. A Latin Square design of 81 experimental plots was laid out, with three treatments: an uncultivated control, a single cultivation, and annual cultivation (Figure 10-2). The first cultivation treatment was applied in November 2005. Treatments 1 & 2 were cultivated to a depth of 10 cm using an edging tool and digging fork to cut out, turn over, and break up turves. For treatment 2, this cultivation was repeated annually, in May 2006- May 2008.



	1	2	3	4	5	6	7	8	9	
9	2	1	0	2	1	0	2	1	0	
8	0	2	1	0	2	1	0	2	1	
7	1	0	2	1	0	2	1	0	2	
6	2	1	0	2	1	0	2	1	0	
5	0	2	1	0	2	1	0	2	1	
4	1	0	2	1	0	2	1	0	2	
3	2	1	0	2	1	0	2	1	0	
2	0	2	1	0	2	1	0	2	1	
1	1	0	2	1	0	2	1	0	2	

Legend
🟦 0 - not cultivated
🟥 1 - cultivated once
🟩 2 - cultivated n times
🟨 buffer

Figure 10-2. Replicated Latin Square experimental design, showing 11 x 11 m area with three treatments applied to 1 x 1 m plots in a 3 x 3 Latin Square, repeated 3 x 3 times.

Soil carbon measurements

Immediately following cultivation in November 2005, soil samples were taken from all plots for analysis of carbon content. Cores were removed by inserting sections of plastic tubing into the soil, and then cutting these out with a knife. Cores were 8 cm deep x 3.8 cm diameter. Samples were analysed for total carbon by loss on ignition (LOI, %) and bulk density (g soil dry mass per cm3). A sub-sample of 18 cores were analysed using an Elemental Analyser for carbon and nitrogen content. These data were used to establish the relationship between LOI and carbon content (C, %):

$$C = 0.497 \cdot \mathrm{LOI}$$

which was applied to the other samples to calculate carbon content. The procedure was repeated twice in 2008 in May and October (approximately 2½ & 3 years after initial cultivation), using the same method except that (i) cores that were 10 cm deep x 5 cm diameter were used, (ii) the dried soil was sieved through a 2mm sieve to separate fine earth from roots, which were analysed separately and (iii) in October, a more intensive sampling of the innermost 3 x3 square was carried out. A sub-sample of soil from both re-sampling dates in 2008 were analysed by Elemental Analyser for carbon and nitrogen content.

Soil respiration measurements

A dynamic closed-chamber system (EGM-4, PP Systems, Hitchin, UK) was used to measure soil respiration on each of the 81 plots in October 2005, prior to the treatment being applied, and after 6, 12, 18 and 36 months. An opaque chamber 10 cm in diameter and 15 cm in height was pressed into the soil. An internal fan provided mixing whilst air was pumped through the chamber and an infra-red gas analyser in a closed circuit. The chamber was left in position until a rise of 50 ppm CO_2 was measured, usually ~70 s. The soil respiration rate, *R*, from the soil was calculated as

$$R = \mathrm{d}CO_2 / \mathrm{d}t \cdot w$$

where $\mathrm{d}CO_2 / \mathrm{d}t$ is the rate of increase in CO_2 with time (µmol $\mathrm{mol}^{-1}\ \mathrm{s}^{-1}$), and *w* is the system volume: area ratio in units of mol air m^{-2}.

Corrections to this equation, using polynomial functions of time to correct for effects of leaks were investigated but made little difference. Volumetric soil moisture was measured at the same time using a handheld TDR probe (Hydrosense, Campbell Scientific Ltd.)

N_2O and CH_4 flux measurements

N_2O and CH_4 fluxes were measured in May 2006 and May 2008 using static closed chambers (Clayton *et al.* 1994). One chamber (volume 25120 cm^3, area 1256 cm^2) was located in each of the plots. The chambers were closed for 60 min with an aluminum lid. Gas samples were collected in portable evacuated aluminium vials in 2006, and into tedlar bags inn 2008. Samples were analyzed for N_2O by electron capture and for CH_4 by flame injection gas chromatography.

10.3 Results and Discussion

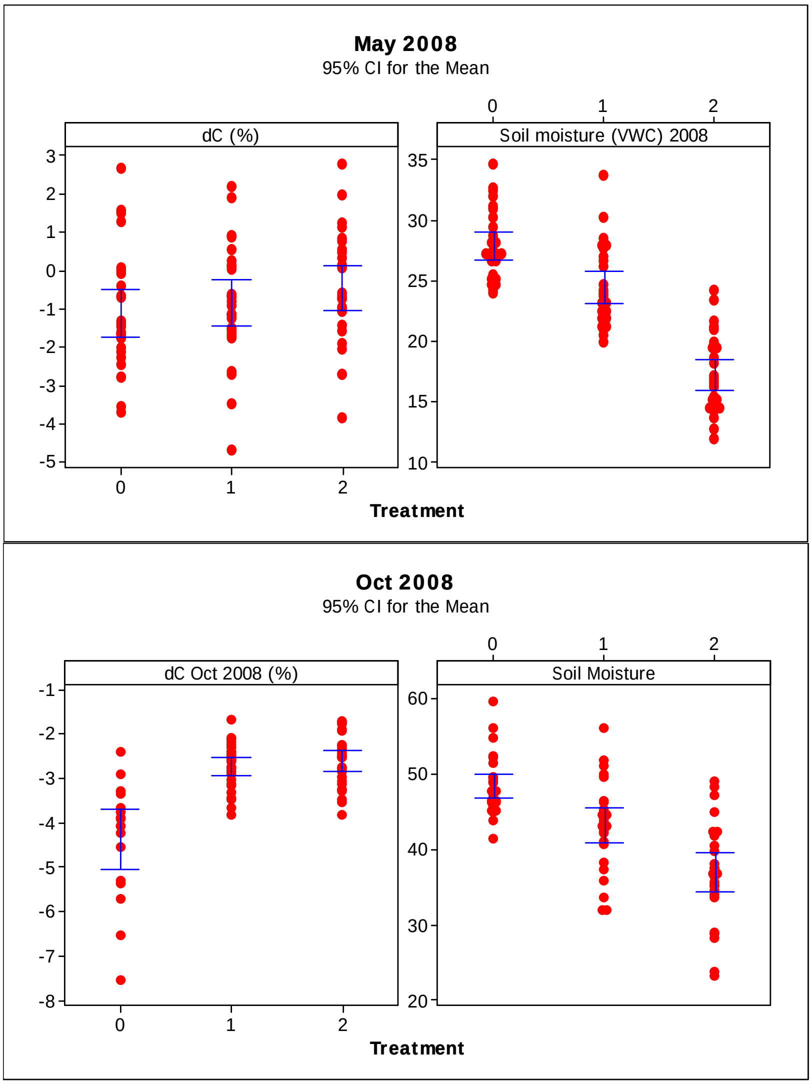


Figure 10-3 Plots showing the change in carbon content (dC, %) and volumetric soil moisture, by treatment, measured in May and October 2008, 2½ and 3 years after the first cultivation, respectively. Treatments are: 0 – uncultivated control; 1 – cultivated once; 2- cultivated annually. Error bars show 95 % confidence intervals for the treatment means.

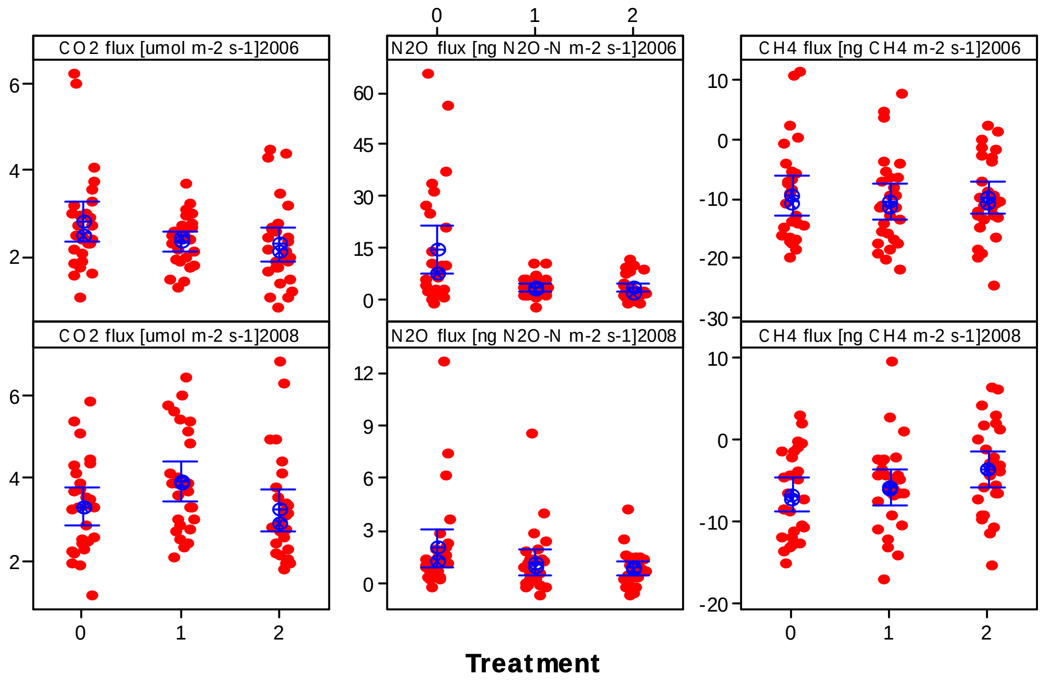


Figure 10-4 Plots showing the fluxes of CO_2, N_2O, and CH_4 by treatment, measured in May 2006 and May 2008, six months and 2½ years after the first cultivation, respectively. Treatments are: 0 – uncultivated control; 1 – cultivated once; 2- cultivated annually. Error bars show 95 % confidence intervals for the treatment means.

The initial measurements in October 2005 showed that there were no significant differences in soil carbon or respiration rates between the plots allocated to the different treatments, prior to cultivation (data not shown). CO_2 emission rates measured in May 2006 were less than half those measured in October 2005, showing a clear effect of the removal of the vegetation and the root respiration component. Given that there had been no vegetation or litter input (except for weed growth between herbicide treatments), all plots were expected to lose soil carbon. The anticipated effect of cultivation was to increase this loss. Figure 10-3 shows that, in fact, the control plots tended to lose more carbon than the cultivated ones, and this difference was highly significant in the October re-sampling (p<0.001). The most likely explanation for this is the significant drying in the cultivated plots (Figure 10-3), which could lead to a reduced decomposition rate by limiting microbial activity. Presumably this drying was brought about by cultivation producing a much rougher surface, exposing a larger soil surface area for evaporation. This is weakly reflected in a decreased bulk density in the annually cultivated plots, by breaking up the soil into less dense aggregates.

The cultivated plots showed significantly lower N_2O emissions than the cultivated treatment (Figure 10-4 , p=0.05), and this was strongly correlated with soil moisture (Figure 10-5 , p<0.001). N_2O production in soils is complex, as it occurs as a consequence of both the oxidative process of nitrification and the reductive process of denitrification (Granli and Bøckman 1994). Low soil moisture and coarse soil texture generally promote nitrification, whereas high soil moisture, fine soil texture and high organic C content promote denitrification, although both processes may go on simultaneously within soils (Davidson 1991). Although the negative effect of cultivation on denitrification may to some extent be counter-balanced by a positive effect on nitrification, the net effect is generally a reduction in N_2O production, and this is seen here.

Figure 10-4 also shows that these soils were generally sinks for CH_4, as expected in aerobic soils, where CH_4 is taken up through oxidation by methanotrophic bacteria. This sink might be expected to be larger in the more aerobic, cultivated plots, but no significant difference in CH_4 fluxes was found in 2006, and CH_4 uptake was significantly reduced by cultivation in 2008. Again, this could be attributable to the low soil moisture in the cultivated plots drying reducing microbial activity.

Figure 10-5 shows a strong relationship between the change in soil carbon (*dC*) and bulk density, with a significant slope in the cultivated treatments. Figure 10-5 also shows a strong relationship between bulk density and soil moisture in the annually cultivated treatment, but this is not clear in the other treatments.

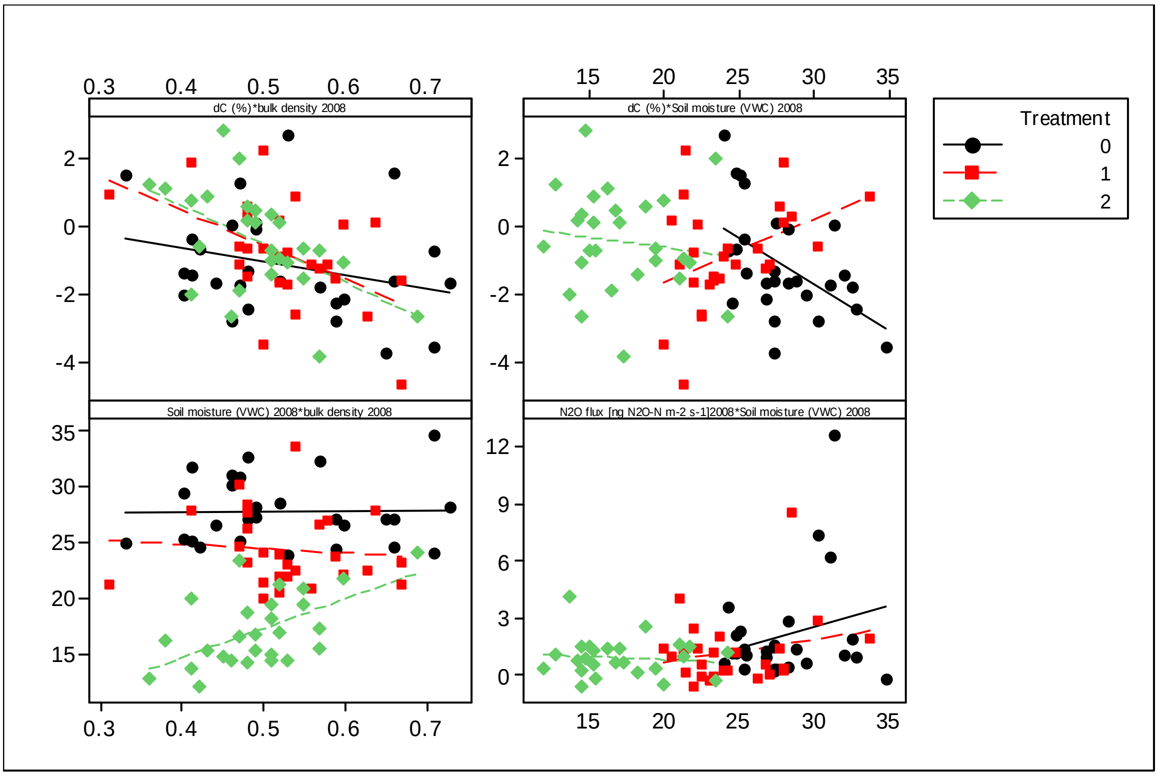


Figure 10-5 Relationships between the change in carbon content (dC) and bulk density and soil moisture (upper row), and between soil moisture, bulk density and N2O flux measured in May 2008. Treatments are: 0 – uncultivated control; 1 – cultivated once; 2- cultivated annually. Least-squares regressin lines for each treatment are shown.

To summarise these results, cultivation appears to have had a consistent effect across the plots, reducing bulk density and soil moisture. This has had the effect of reducing decomposition and emissions of CO_2 and N_2O. The aim of this experiment was to isolate the direct effect of cultivation *per se* on soil carbon losses. However, by designing an experiment to explicitly quantify this in an atypical system (without plant cover), we necessarily compromise the wider applicability of this expermemt. The direct extrapolation of these results to real agricultural land use changes is questionable, as there are likely to be important differences when a crop canopy is maintained on the soil surface. Most importantly, when a grass or crop canopy is maintained, much less evaporation comes directly from the soil surface, and changes to the soil surface roughness will have less impact on soil moisture. Secondly, soil at this particular site may be more prone to drying out than is generally typical, being shallow and free-draining, and exposed to relatively high winds. This suggests that further work might include a second, recovery stage, wherein the vegetation is allowed to regrow after cultivation. A wider range of soils should be covered also, including deeper, wetter soils, in less exposed lowland areas.

Bearing in mind the caution needed in extrapolating these results, we can quantify the impact of cultivation on the net greenhouse gas balance of these soils. We combined the loss of soil carbon, CH_4 and N_2O fluxes, multiplied by their global warming potentials (GWPs) to give units of g CO_2-equivalents m^{-2} y^{-1}. GWPs for N_2O and CH_4, their effects on radiative forcing relative to CO_2 over 100 years, were taken as 297 and 23, respectively. Here we calculate the change in GWP relative to the control. The annually cultivated treatment lost 263 g CO_2 m^{-2} y^{-1} less than the control over the experiement. Averaging the N_2O fluxes, the annually cultivated treatment emitted 0.3 g N_2O m^{-2} y^{-1} less than the control. CH_4 uptake was less by 0.1 g CH_4 m^{-2} y^{-1} giving a balance of:

Net effect of annual cultivation on GHG emission

$$\begin{aligned} &= dCO_2 + dN_2O + dCH_4 = dGWP. \\ &= -263 + (-0.3 \times 297) + (0.1 \times 23) \\ &= -263 + (-90) + (2) = -351 \text{ g } CO_2\text{-eq m}^{-2} \text{ y}^{-1}. \end{aligned}$$

Thus, the reduced loss of soil carbon adds to the reduction in N2O emission, to reduce the net emission of GHGs from the cultivated treatment at this point. CO2 is the largest of the three effects. A smaller effect size (but of the same sign) is seen if the soil efflux data is used instead. Changes in N2O emissions are the clearest change statistically, and contribute around one third of the net effect. Changes in CH4 are largely negligible. The implication of these results is that cultivation does not directly accelerate the decomposition of soil organic matter, and may actually impede it, as well as reducing N2O emissions. This has implications for mitigation policies based on changes to tillage practice. Our experimental design lends itself to more complex spatial analysis, eg. spatial REML, but results from this type of analysis were not substantially different.

An attempt to measure the 14C component in respired CO2 was made in November 2006 but failed to capture enough CO2 for 14C analysis. A modification to the method was devised to increase the capture of CO2, using neoprene skirting around the chamber to seal the surrounding soil surface. This has been tested and now works satisfactorily. However, given the results for the differences betweem treatments in soil carbon, the value of these measurements is less clear.

10.4 References

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10.5 Acknowledgements

We acknowledge the co-operation and assistance provided by Alex Moir of the Scottish Agricultural College, Bush Estate.

11. Assessment of land-use change on peatland carbon budgets (WP 2.6)

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11.1 Introduction

Peatlands represent the largest store of carbon in UK ecosystems. The carbon balance of these peatlands will be affected by changes in land use, and they have the potential to act as a major carbon source or sink. Historically, the main land management pressures have come from grazing, burning (management for grouse), drainage and afforestation. In recent years, there has been a major move throughout the UK towards reversal of afforestation and drainage practices: conifer plantations have been removed and the natural hydrology re-established to raise the water table. This is likely to have a major impact on the carbon balance of restored peatlands, although the magnitude and direction of these changes is not clear. Caithness and Sutherland have the largest area of blanket bog in the UK, of which 150000 ha are “severely affected” by drainage, and major initiatives are in place to reverse this (LIFE 2000). Here, we aim to quantify the effect of this reversal in hydrological management on a peatland site in Sutherland, and provide estimates of the impact of these practices at a regional scale. We describe a three-way comparative experiment, with sites that are pristine, drained, and drain-blocked, at the RSPB reserve at Forsinard, Sutherland. Comparision of the carbon balances of the drained, and drain-blocked sites will be used to infer the effect of this peatland restoration practice. The purpose of the pristine site is to give a further control, representing the current background carbon balance in the undisturbed state, which may be responding to changes in climate, CO_2 and nitrogen deposition, but is not affected by land management.

11.2 Site and Methods

The sites are all sub-catchments of the River Dyke near the Cross Lochs, 4 km north-west of the RSPB Visitor Centre at Forsinard Station (58^o 24’N, 03^o 58’W) in Strath Halladale, Sutherland (Figure 11-1). The three sites represent areas of contrasting types of peatland management:

- **Pristine**: Cross Lochs South – a 2 km^2 peatland catchment which drains west from a bog-pool system to the River Dyke.
- **Drain-blocked:** Cross Lochs North – a 2 km^2 catchment containing drain-blocked (80%) and deforested (20%) peatland. Drain blocking using a combination of peat dams and plastic inter-locking sheets occurred during 2002-2003.
- **Drained:** Allt a’Bhunn – located 6 km north of Cross Lochs on the Bighouse Estate, the Allt a’Bhunn catchment consists of a 4 km^2 area of intensively drained peatland. Drainage occurred in the 1960/70s with parallel drains at a spacing of 50 m.

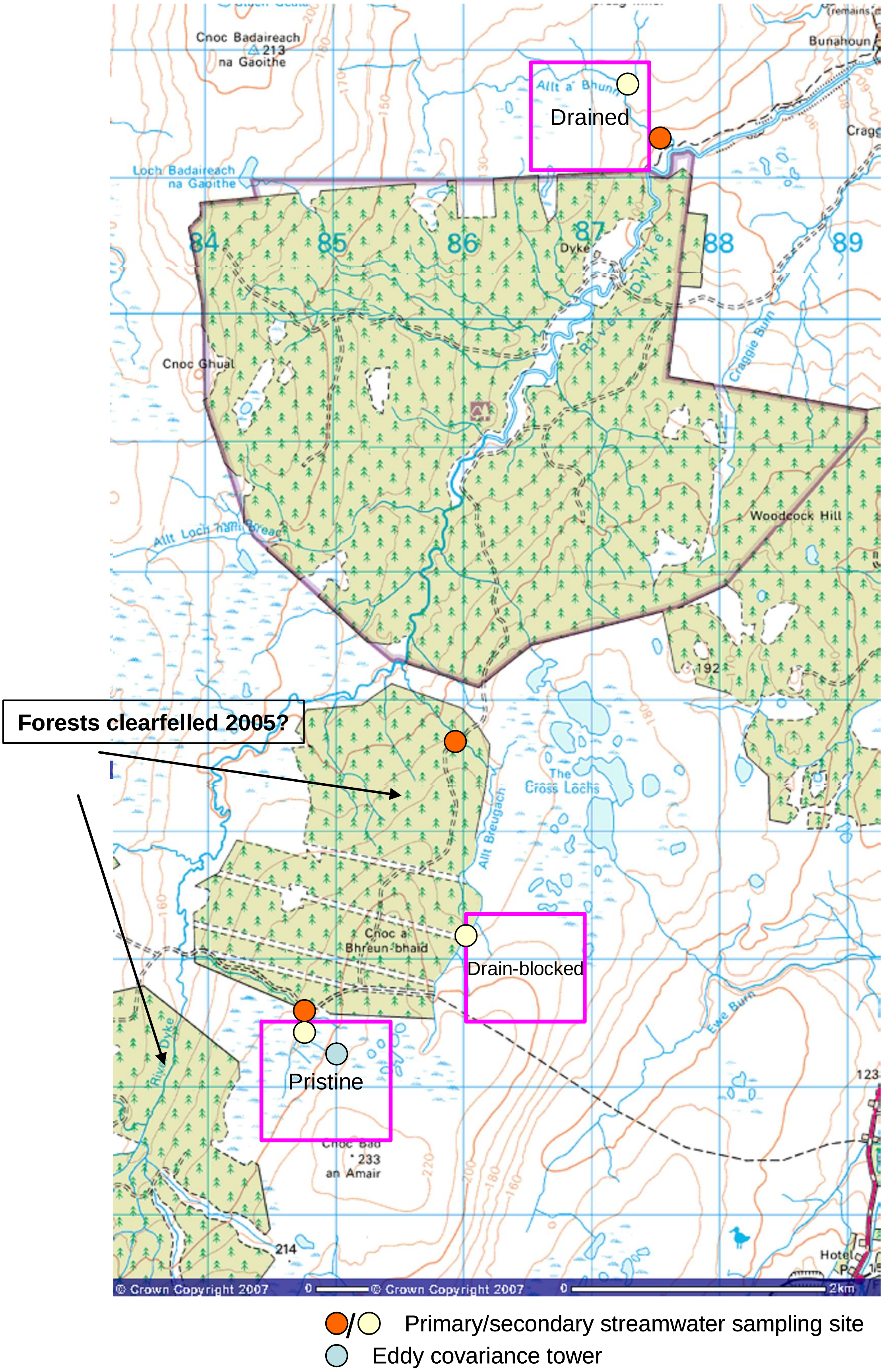


Figure 11-1 Location of the field sites and eddy covariance measurement tower within the RSPB Forsinard reserve, Sutherland.

A micrometeorological approach, eddy covariance, is used to make near-continuous measurements of the surface exchange of carbon dioxide (CO_2) and water vapour at the pristine site. Equipment was installed between 4th February and 10th April 2008. The location of the eddy covariance flux measurement system is shown in Figure 11-1 , to the south-west of the Cross Lochs, on a large expanse of blanket peat with some pool systems typical of Caithness and Sutherland 'Flows' (Figure 11-2).

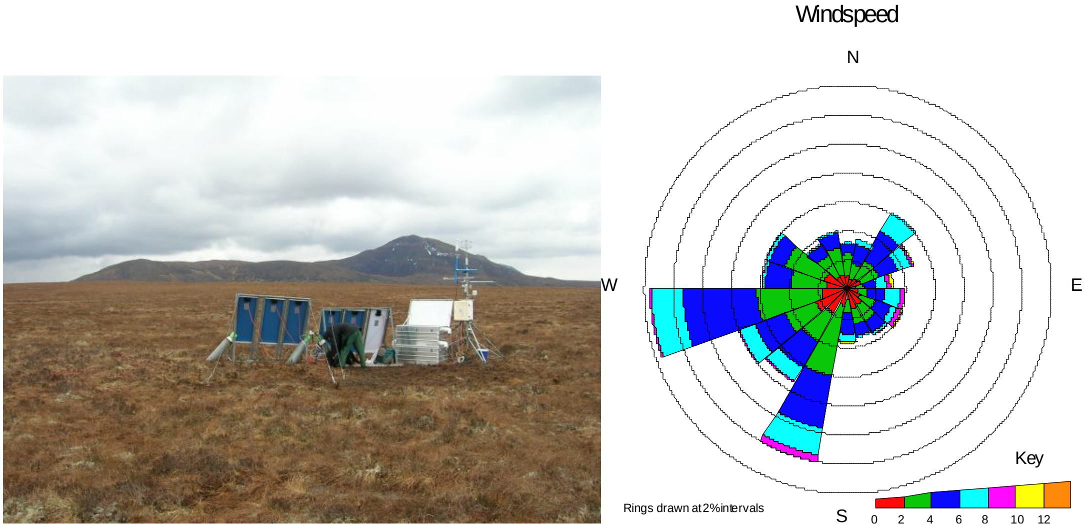


Figure 11-2 (a) Eddy covariance system at the pristine peatland site near the Cross Lochs, Forsinard, Sutherland. (b) Wind rose for the site showing the frequency of wind direction and distribution of wind speed (coloured scale in m s^{-1}).

With the prevailing west and south-westerly wind direction (Figure 11-2), there is a fetch of at least 1 km to the nearest areas of forestry (the forestry boundary on the OS map is somewhat inaccurate and will be re-surveyed by GPS). Details of the instrumental techniques are as in Hargreaves *et al.* 1998 and Hargreaves *et al.* 2003, except that an open-path CO_2 analyser is used here (LI-7500, Licor Corp., Nebraska, USA). In brief, the net flux of CO_2, F_c, is given by:

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

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 10 Hz by a Metek ultrasonic anemometer (Model USA1, METEK GmbH, Elmshorn, Germany), mounted at a height of 3 m. CO_2 and H_2O concentrations are measured by an infra-red gas analyser (IRGA)(LI-7500, Licor Corp., Nebraska, USA) with a response time 40 Hz. A data logger (CR3000, Campbell Scientific Ltd., Loughborogh, UK) logs the data from these instruments and carries out the eddy covariance calculations.

A Campbell 23X-PB datalogger provides remote telemetry via the mobile telephone network, and supporting meteorological measurements including 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 six 80W solar panels. These charge an array of deep-cycle sealed lead-acid batteries with a total capacity of 700 Ah. The datalogger controls power consumption by switching off the sonic and the Licor gas analyser when battery voltage is too low. The system has been running uninterrupted from 10 April 2008 to date.

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:

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

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:

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

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.

Surface fluxes of CO_2 and CH_4 will be measured using chambers at all three sites, as this allows replication and statistical analysis of between-site differences. These chamber methods can also be used to do manipulative experiments, deriving responses to light, temperature, soil moisture, and to investigate spatial heterogeneity. Fifty chambers have been constructed, and are being installed during summer 2008. The fluvial fluxes are being measured at all three sites by continuous monitoring of discharge rates and total carbon content in fortnightly water samples. Fluxes are calculated as product of discharge rate and carbon content, divided by the catchment area. Continuous monitoring began in July 2007, in collaboration with the Environmental Research Institute.

11.3 Results

Figure 11-3 shows the response of CO_2 flux to quantum flux (‘light response curves’), demonstrating the short-term dependence of ecosystem photosynthesis on incident radiation. The relationship is suitably clear and linear, allowing us to have confidence in the working of the measurement system, and to gap-fill and extrapolate measurements using a simple statistical model based on light and temperature dependence. Figure 11-4 shows the change in soil water status at the site up to the end of 2008. There is a clear response of both water table depth and soil water content to rainfall and intervening dry periods. The influence of the changes in these other variables on the light responses shown in Figure 11-3 will be the basis for more detailed analysis, and will permit interpolation and extrapolation.

The methodology described above was used to fill gaps in the data (almost exclusively due to rainfall events interrupting the working of the sonic anemometer and open-path gas analyser). The results are shown in FigFigure 11-5 , which clearly shows that the site is accumulating carbon over this spring-early summer period, and begins losing carbon around October. The site is expected to be a net sink of around 100 g C m^{-2} y^{-1} when the first year’s full data set is analysed. The values are in line with, but slightly higher than previous measurements over UK peatlands at Auchencorth Moss (Hargreaves *et al.* 2003) and Moor House (Levy 2005).

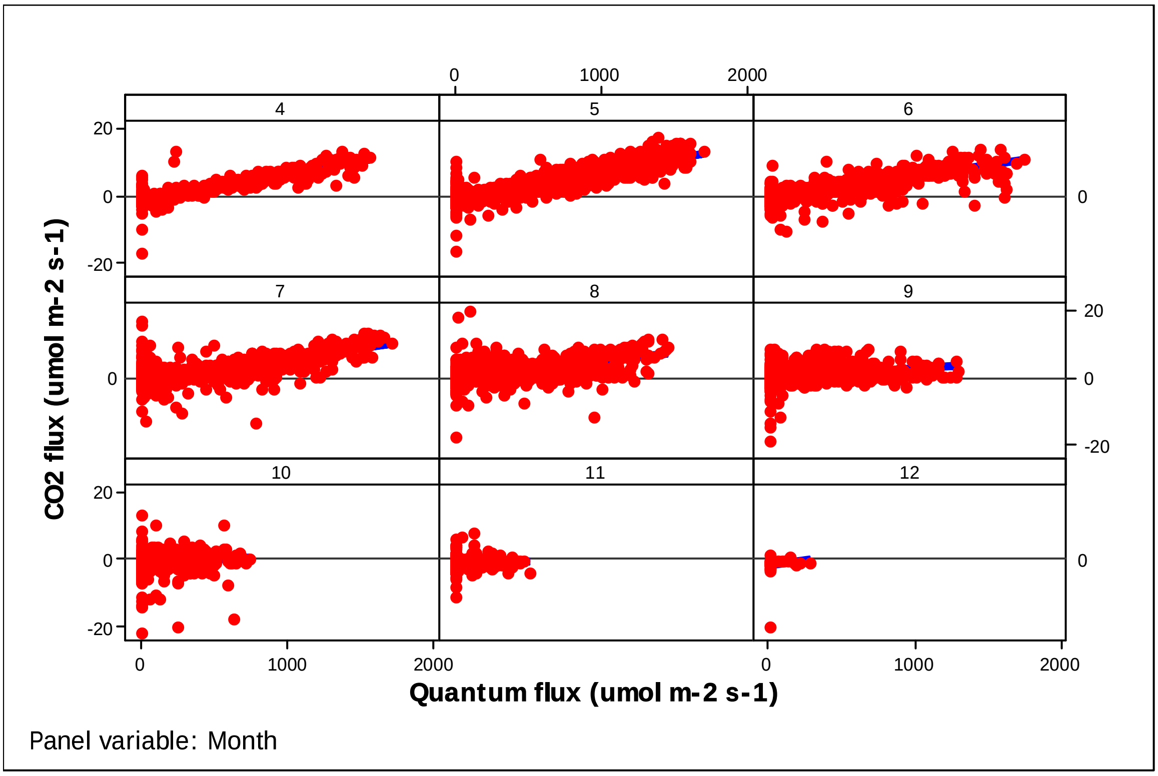


Figure 11-3 Response of ecosystem CO2 flux to quantum flux (light), from half-hourly eddy covariance measurements at the pristine peatland site near the Cross Lochs, Forsinard, Sutherland. Panels show data for each month between April and December (months 4-12) 2008. Linear regression lines are overlaid.

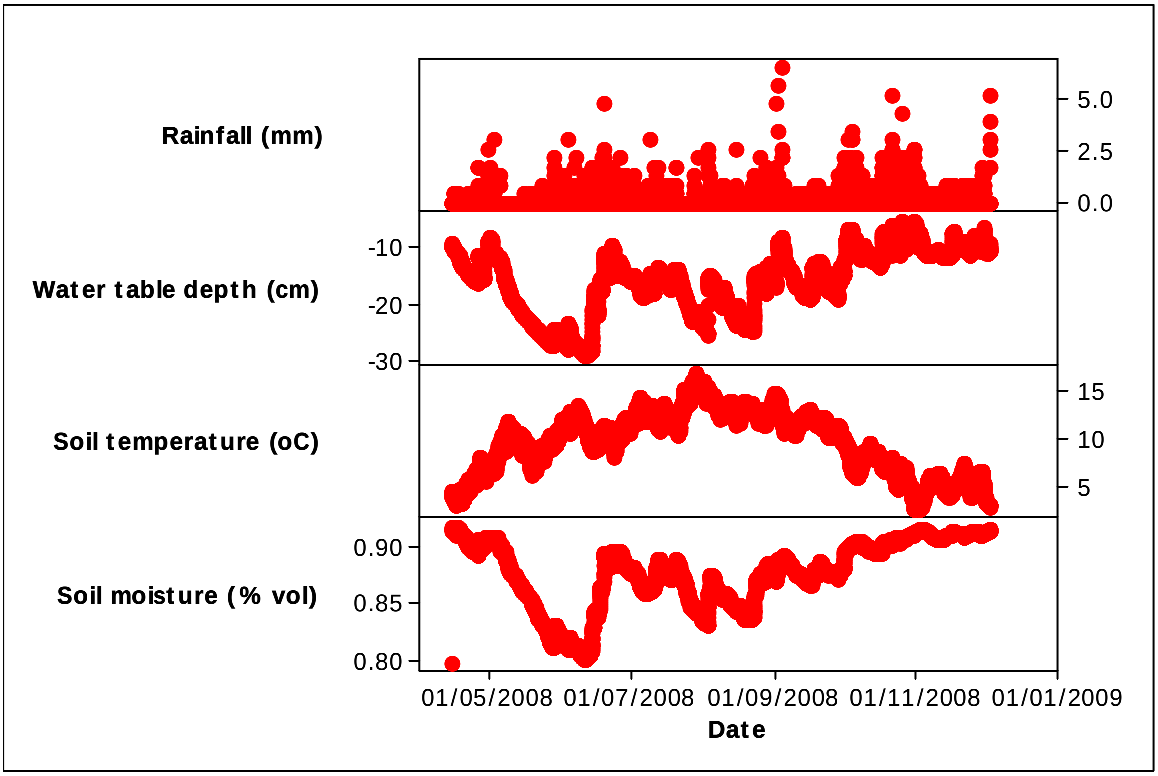
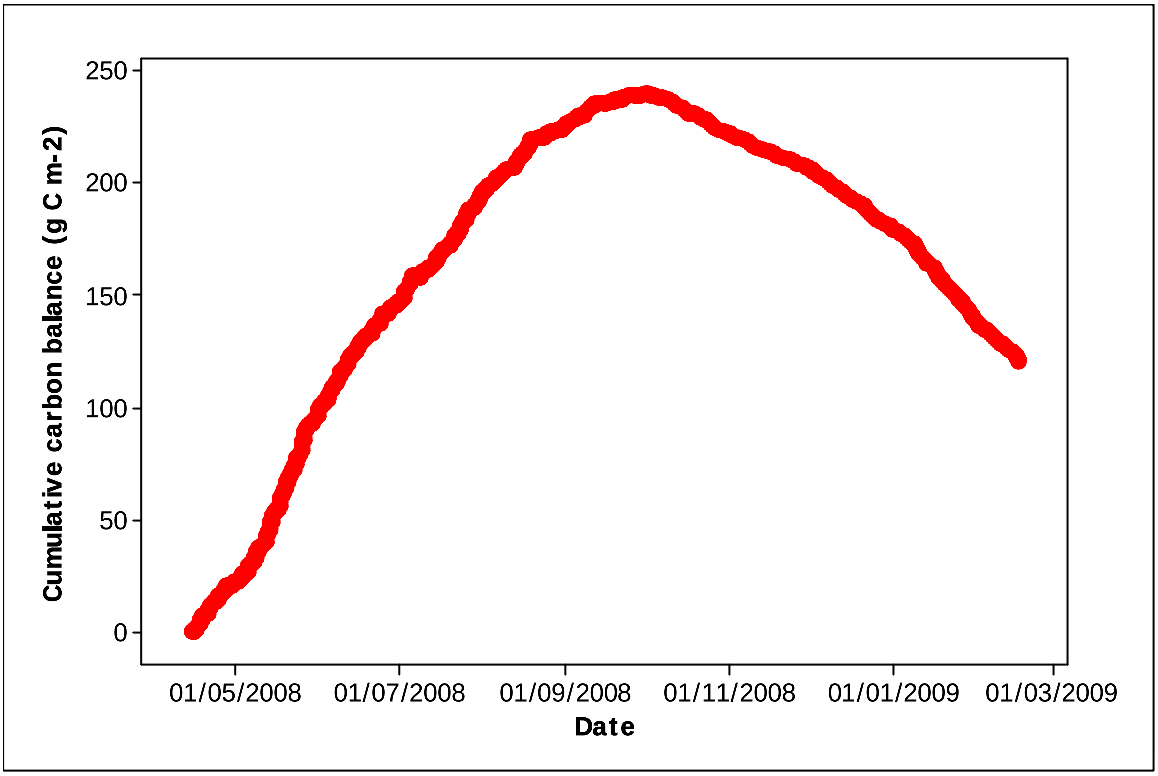


Figure 11-4 Measurements of rainfall, water table depth and volumetric soil water content (VWC) at two depths at the pristine peatland site near the Cross Lochs, Forsinard, Sutherland.



Fig

Figure 11-5 Cumulative carbon balance of the pristine peatland site near the Cross Lochs, Forsinard, Sutherland, based on gap-filled eddy covariance measurements (land-atmosphere flux only).

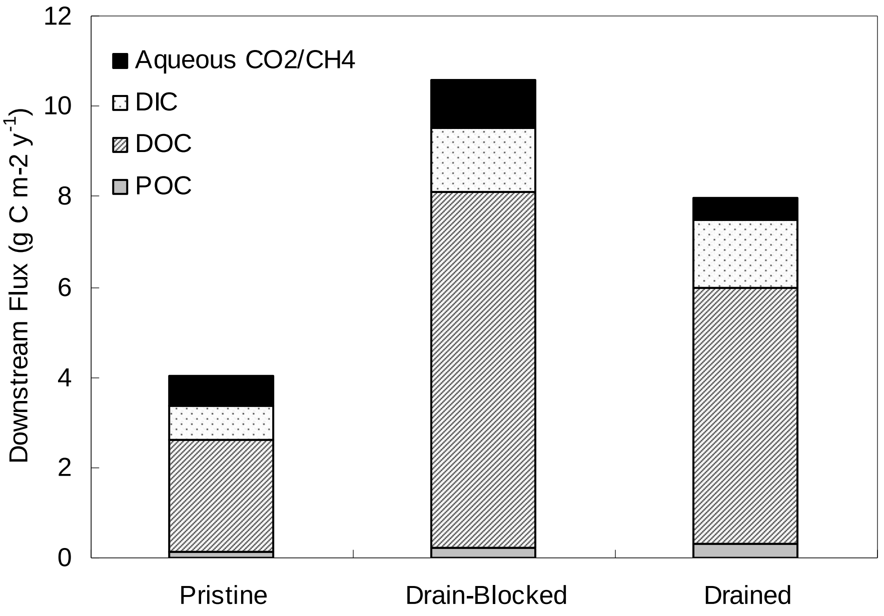


Figure 11-6. Comparison among catchments of the fluvial fluxes of carbon in the form of aqueous CO_2 & CH_4 dissolved inorganic carbon, (DIC), dissolved organic carbon (DOC) and particulate organic carbon (POC).

The provisional fluvial fluxes in Figure 11-6 are small in magnitude relative to the atmospheric term, but show the least export from the pristine site. More carbon is exported from the drain-blocked site than the drained site, which is unexpected, and requires further analysis. It should be emphasised that these are provisional fluxes, and a longer time series and more accurate definition of the catchment areas may change the results substantially.

Extrapolating the measurements to predict 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, our field measurements produce the data required for developing and validating a process-based model of carbon dynamics under these conditions. 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. Long-term records and GIS databases are available for many of the critical input variables for modelling: meteorology, hydrology, stream water chemistry and vegetation. These will be used to extrapolate estimates of the carbon balance over the regional scale and longer time spans.

The originally proposed ‘before and after’ experimental design had the disadvantage that differences in climate before and after drain blocking could not be accounted for. The new design has the advantage that all sites experience the same climate over the course of the experiment, and that the comparision with a pristine site can be included to give an appropriate baseline. The disadvantage is that we ascribe differences to a treatment effect when there could be inherent differences between sites. This problem is minimised by choosing sites as close together and as comparable as possible in all other respects. The sites chosen at Forsinard are very well-suited in this respect, all being within a few kilometres and otherwise similar.

11.4 Collaboration with partner institutes

In addition to the study of carbon fluxes, the following measurements are being or will be made by contributing partners:

- ERI – impact of peatland management on vegetation. This will involve detailed site-specific survey work and vegetation mapping aimed at examining successional change within the bogs in response to restoration. The results will also enable the upscaling of chamber CO_2 and CH_4 flux measurements to the whole catchment.
- RSPB (Norrie Russell, Neil Cowie) – quantification of the impact of peatland management on biodiversity. The work is primarily based on the use of pitfall traps to measure invertebrate distribution and density (as a food source for birds).
- Macaulay (Rebekka Artz and Martin Sommerkorn) – below ground measurements of the affects of peatland management on soil ecosystem functioning. This will involve quantifying carbon turnover, C/N interactions and soil microbial diversity.

The primary aim of the project is to better understand the impact of peatland restoration on carbon cycling and to inform policy makers and land managers about ways of optimising peatland carbon storage and biodiversity. Through the establishment of infrastructure and long-term monitoring, our aim is to encourage researchers and students to participate in the study of one of the most important areas in the UK for both carbon storage and biodiversity, but one of the least understood.

11.5 Acknowledgements

We acknowledge the co-operation and assistance provided by ERI Thurso and the RSPB.

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12. Statistical analysis of NSI soil carbon changes in relation to climate and land management changes (WP 2.8)

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12.1 Introduction

The National Soil Inventory (NSI) consists of 5662 sites that were sampled for soil in 1980, 40% of which were resampled between 1995 and 2003. Large losses of carbon from soils across England and Wales have been found between the two samplings (Bellamy et al. 2005). This rate of loss was found to increase linearly with increasing soil carbon content for the whole country and across all land use. That carbon loss is a function of soil carbon is not surprising, because at larger quantities of soil carbon there is more carbon to lose. However, we expected that these rates of loss would be different across land uses as land use is known to significantly affect the quantities of soil carbon and the rate of carbon turnover. It was hypothesized that our findings of “no land use effect” were the result of only a broad land use class being associated with each of the NSI sites at the time of sampling. We expect that changes in detailed land management (for example cultivation practices, fertilizer practices, lengths of grassland-arable rotations, animal stocking rates, moorland burning, etc. King et al. 2004) within these broad land use categories will undoubtedly contribute to the carbon changes and there are likely to be complicated interactions between land use/management and climate change.

The overall aim of this study was therefore to determine if there is sufficient available existing detailed information at some of the NSI sites to determine the effect of specific land managements on the rate of carbon change using statistical inference. Effective statistical analysis will require us to identify sites with detailed information on land management and its changes over the period 1980 to 2003 and more particularly sites where management has remained relatively stable.

The first objective of this project was therefore to identify NSI sites where sufficient quantitative information on land management is available. Our second objective was, for these sites, to investigate the relationships between the changes in soil carbon and differences in land management, taking into account as far as possible variation in soil, ecosystem and other variables in the dataset.

12.2 Methods

Statistics

The statistical analyses used were Analysis of Variance and Analysis of Covariance – which are both kinds of general linear model. An Analysis of Variance compares mean values of the dependant variable (the rate of change of carbon) at each level of a fixed effect (the different land management classes). An Analysis of Covariance does exactly the same, but allows for the variation in a continuous variable (the mean of the organic carbon measured at the first and second sampling) and was used when the land management was independent of soil carbon content. In that case it was necessary to remove the effect of, for example, a particular class having all high carbon sites. The models fitted are valid only if several assumptions about the data hold. These are that:

- the covariate is normally distributed,
- the dependant variable is normally distributed within the groups of the fixed effects
- the variance within the groups is constant.

These assumptions were tested for the datasets analysed here and transformations carried out and extreme values excluded where necessary.

Identification of study sites

A wide range of sources of information was examined:

A. Aerial photographs were available for an area of the Yorkshire Moors for a number of years between 1960 and 2000. Three NSI sites that had been resampled were within the area of the photographs for the years 1989 and 1995. For the two upland heath sites it was possible to identify the sites on photographs taken in 2000 although the rectification was not very good. The photographs were examined and it was concluded that the site under permanent grass was still under permanent grass in 1995 – two years before the resampling. However this did not give us any information on the management – such as stocking rates or hay cutting regime. More interesting were the two "upland heath" sites where it was apparent that burning had occurred at or close to both sites between the two sampling events.

B. The Countryside Survey[1](CS) has 1314 sites where measurements were taken in 1990 and 1999 in England and Wales and for which some management data was available. The locations of these sites were compared to the NSI sites and no CS site was closer than 1.9km to a resampled NSI site, so this dataset will not provide any relevant information.

C. Eleven upland NSI sites in Wales that had been resampled were visited again in 2005 and soils sampled as part of an MSc project (Vernik 2005). Unfortunately due to limited resources the land management history at these sites was not investigated so these sites cannot be included in our analysis.

D. Fourteen resampled NSI sites within the broad land use class 'Arable' were revisited in 2003 to collect data for a PhD project (Verheijen 2005). Some information on land management before and between the two samples was gathered. This information included: when straw burning was stopped, whether straw was incorporated or removed from the field, tillage techniques, manure applications and some information on cropping cycles.

E. There are some permanent experimental sites across England and Wales for which detailed land management information is available. Four such sites which are described in a DETR report (contract EPG1/1/39) (2000) were compared to the resampled NSI points but none of these sites are within 1km of any NSI site.

F. Of the 234 resampled NSI points which were under woodland at the second sampling there were 75 which fell within woodland plots with forest management information. The land use at the second sampling of the NSI

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[1] *Data from Countryside Survey provided by the Centre for Ecology and Hydrology under license (www.CS2000.org)*

was used to identify forest sites to maximise the number of sites. The following management variables were provided by Forest Research:

- Tree species
- Soil type
- Altitude
- Terrain condition, terrain roughness and terrain slope
- Cultivation strategy
- Land use
- Storey
- Origin of the trees
- Propagation technique
- Planting year
- Area of the component and percentage of sub-compartment occupied by the component
- Rotation
- Mixture
- Type of plantation
- Number of species
- Wind hazard classification
- Initial spacing
- Stocking assessment
- Basic yield model
- Thinning cycle
- Percentage of model volume at time of fell
- Percentage of model DBH at time of fell
- Habitat

The date of assessment of these plots was between 1999 and 2003 which is at about the time of the second sampling of the NSI woodland sites.

12.3 *Results*

Sites with burning

The techniques of Yallop et al. (2006) were used to determine the age of the burnt areas at the NSI sites identified from aerial photographs (Table 1). At both sites where burning had occurred, large losses of soil carbon content were seen (-1.59 g/kg/yr and -3.58 g/kg/yr). However, with only two sites it is impossible to determine whether this loss in carbon was due solely to the burning practices or an interaction between that and climate change. Data from a similar upland site which is part of the Environmental Change Network (ECN) and which has not been burnt was obtained but the soil carbon had only been measured on one occasion so no comparison could be made.

Table 12-6 Upland sites on Yorkshire Moors identified from aerial photographs

NSI Site ID	Date of original sampling	Date of resampling	Original OC content (g/kg)	Resampled OC content (g/kg)	Rate of change OC content (g/kg/yr)	Land use	Management identified from aerial photos
11283	08/03/1983	31/03/2003	503	471	-1.59	Upland Heath	Burnt 1-3yrs prior to 1989 recovering

							1995 not burnt up to 2000
11284	27/01/1983	10/03/1997	58	54.4	-0.25	Permanent Grassland	Permanent grass 1989/ hay cut 1995
11143	08/07/1981	11/04/2003	548	470	-3.58	Upland Heath	Not burnt by 1989 still not burnt by 1995 but very close to burnt areas in both years

Arable sites from PhD study

The first task was to estimate a rate of change at each of the 14 sites using the three observations of OC content. This was done by fitting a straight line to the three points and using the slope to estimate the rate of change. The mean value of carbon over the three samples was also calculated. At no individual site were the rates of change significantly different from zero (Table 2).

Table 12-7 NSI sites resampled in 2003

Site number	Mean OC g/kg	SE of mean OC	Rate of change of OC (g/kg/yr)	SE of rate of change	Brief management summary
1	10.90	0.44	0.02	0.07	Straw inc. 1995 onwards
3	31.93	2.03	0.28	0.26	Straw inc. 1992 onwards
4	24.27	1.17	0.16	0.12	End burn 1993 no inc.
5	15.87	1.58	0.24	0.13	Straw inc. 1992 onwards
7	23.23	1.91	-0.26	0.18	3yr ley 1987-1990 no inc.
9	13.87	0.45	0.06	0.01	Straw inc. 1987 onwards
28	18.83	0.69	0.03	0.11	Straw inc. 1992 onwards
32	16.50	0.26	0.04	0.00	Straw inc. 1985 onwards
60	14.73	0.87	0.15	0.06	End burn. 1990 no inc.
63	22.00	1.00	-0.13	0.06	Straw inc. 1997 onwards
65	15.43	1.94	0.31	0.02	Straw inc. 1992 onwards
67	21.63	3.34	-0.28	0.51	Mangles then straw inc. 1997 onwards
72	21.80	0.83	-0.05	0.12	End burn 1983 no inc.
74	23.93	0.64	0.03	0.09	Straw inc. 1984-1990

The land management at each site was different and changed at different times over the interval between the first and third sampling. A key management that could influence the OC content of the soil is straw incorporation and a brief summary of the management of straw at each site is given in Table 2. All sites were under continuous cereals except sites 7 and 67. Four sites had no incorporation of straw, at three sites straw was incorporated from 1992, at three sites incorporation was not started until 1995/1997 whereas at two sites incorporation was started in 1985/1987. One site had straw incorporated from 1984 to 1990 then stopped. It was therefore very difficult to make inferences regarding the size of effect of straw incorporation on soil OC change using these data.

Forestry sites

Data on change in carbon over about twenty years is available for 234 woodland sites from the NSI, 111 under coniferous woodland (CO) and 123 under deciduous/mixed woodland (DC). The mean rate of change of organic carbon for sites under CO is higher (-0.112±0.032 g/kg/yr) than for sites under DC (-0.042±0.023 g/kg/yr). However if the original carbon content of the soil is taken into account, there is no significant difference between the two groups (using Analysis of Covariance with log mean OC as a covariate). Of these 234 NSI sites 75 sites have management information supplied by Forest Research (64 under CO and 11 under DC) (Figure 12-2).

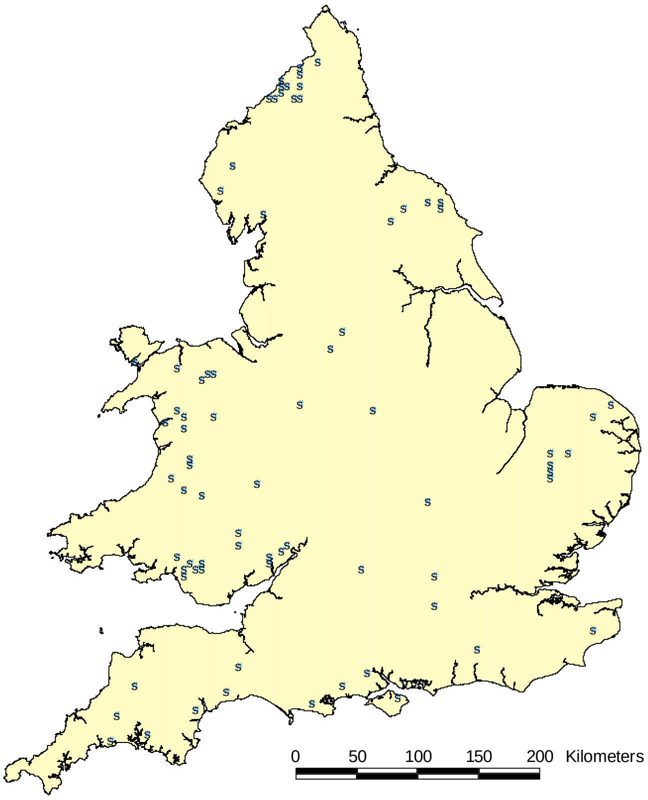

Figure 12-2: NSI resampled woodland sites with Forest Research management information

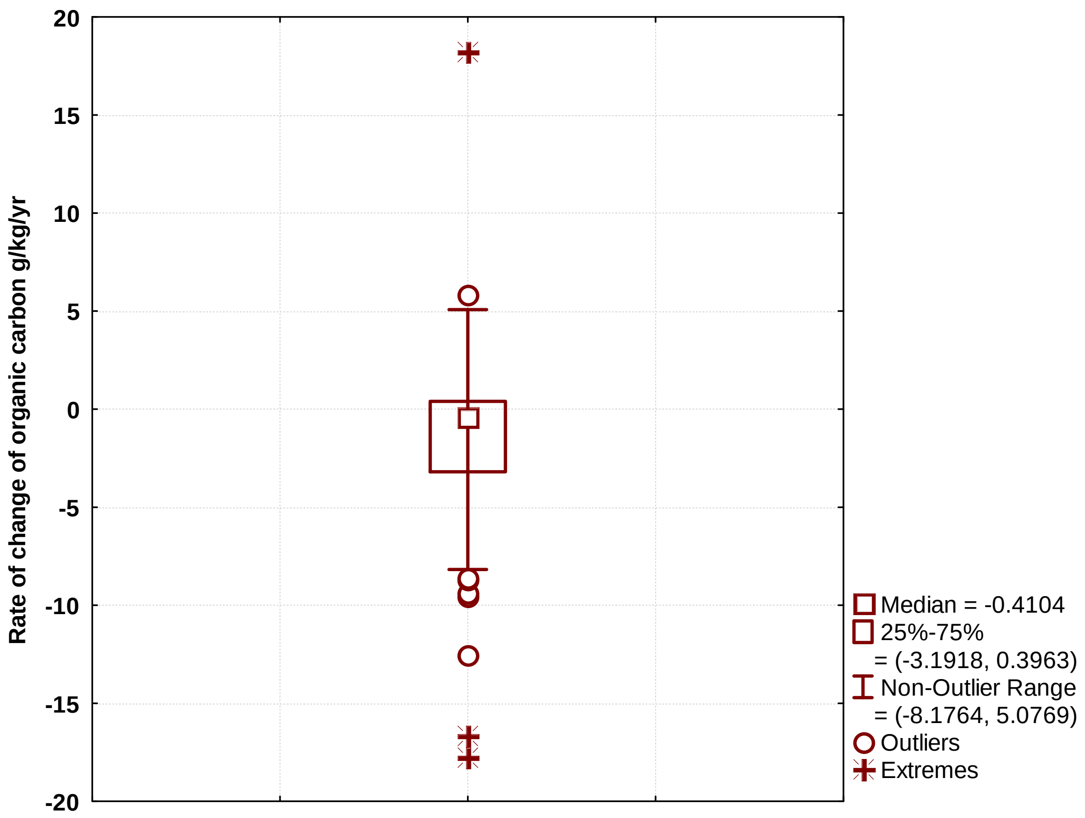

Figure 12-3 Rate of change of OC for all sites with management data

Figure 12-3 shows a box plot of the rate of change of all the 75 sites with management information. The three sites identified as “extreme” were excluded from the analysis. The management information for the remaining 72 sites was not complete. Those variables with partial records or with only a few sites per subclass were not considered for analysis.

Table 12-8: Management variables used in analysis

Variable	**Description**	**Classes**	**Number of NSI sites**
Terrain condition	Ground conditions for carrying out management (dry/wet boundary is 1140mm of annual precipitation).	1 Very good (dry sands and gravels)	11
		2 Good (firm mineral soils)	23
		3 Average (soft mineral or ironpan soils in drier areas)	19
		4 Poor (Peaty gleys in drier areas; soft mineral soils in wetter areas) and 5 Very poor (peaty gleys in wetter areas; deep peats) (see footnote)	16
Rotation	A period of time normally sequential (e.g. First or second rotation) where an even aged stand is planted/regenerated, matures and is then felled. It is also used to show ancient woodland and long term or historic woodland	1 First Rotation on formerly bare land	32
		2 Second and subsequent Rotations	15
		S Ancient semi-natural woodland	0
		9 Historic woodland (see footnote)	20
Date of planting			64

Notes:

Class 5 only had 1 point and was merged with class 4.

Historic woodland is woodland that was originally planted decades ago but can have trees planted within the stand in more recent years

Table 12-8 shows details of the management variables for which enough information was available and where the number of sites in each subclass enabled a statistical analysis to be carried out. These are: terrain condition (4 classes) and rotation (classes 1, 2 and 9 only) and year of planting. Table 4 shows the descriptive statistics for both terrain condition and rotation. The mean interval between sampling for the NSI sites identified was 21.5 years.

Table 12-9: Descriptive statistics of the rate of change of organic carbon (g/kg/year) for each class within each variable.

Variable	Classes	Number of sites	Mean g/kg/yr	Median g/kg/yr	Min g/kg/yr	Max g/kg/yr	SD	Skewness	Kurtosis	Mean original OC g/kg
Terrain condition	1 Very good (dry sands and gravels)	11	-0.08	0.04	-2.51	1.72	1.18	-0.74	0.67	34.74
	2 Good (firm mineral soils)	23	-1.83	-0.59	-9.55	2.37	3.27	-1.19	0.77	80.00
	3 Average (soft mineral or ironpan soils in drier areas)	19	-0.33	0.16	-5.57	5.83	2.74	0.38	1.22	87.98
	4 Poor (Peaty gleys in drier areas; soft mineral soils in wetter areas) and 5 Very poor (peaty gleys in wetter areas; deep peats)	16	-3.00	-1.17	-12.59	3.89	4.78	-0.57	-0.70	171.32
Rotation	1 First rotation on formerly bare land	32	-2.61	-1.07	-12.59	2.37	3.83	-1.06	0.20	122.57
	2 Second and subsequent rotations	15	-1.22	-0.81	-6.24	3.89	2.71	-0.03	-0.27	104.34
	9 Historic woodland	20	0.01	0.20	-8.71	5.83	2.83	-0.92	5.11	53.96

In general, all the terrain condition classes identified in forested areas have lost organic carbon. Carrying out an Analysis of Variance showed there were no significant differences in the rate of loss of carbon between the terrain classes.

The ‘rotation’ in this woodland context is a period of time, normally sequential (e.g. First rotation or second rotation), where an even aged stand is planted/regenerated, matures and is then felled. The three classes identified in this dataset were first rotation, second and subsequent rotations (combined) and historic woodland. Historic woodland is woodland that was originally planted decades ago but can have trees planted within the stand in more recent years. Table 12-5 shows the Analysis of Covariance table. It can be seen that there are no significant differences between the rotation classes (p>0.05)

Table 12-10 Analysis of covariance of rotation class

Effect	SS	Degrees of freedom	MS	F	p
Intercept	88.8584	1	88.8584	9.900	0.0025
Log (Mean OC)	144.0807	1	144.0807	16.052	0.0002
Rotation class	45.0291	2	22.5145	2.508	0.0895
Error	565.4601	63	8.9756		

However Table 12-9 shows the mean rates of change of OC for the three classes adjusted to the mean value of OC and it can be seen that woodlands which were in their first rotation (i.e. where trees had been planted on bare ground at some point before the second sampling of the NSI) were found to be losing significant amounts of carbon: -2.38±0.53 g/kg/yr, which is a relative rate of about -0.44% per year (relative to existing soil carbon content). This can be compared with a mean change of -0.94±0.78 g/kg/yr for those sites in second or later rotations and -0.58±0.69 g/kg/yr for historic woodlands, neither of which were significantly different to zero. Of the 32 sites in the first rotation class only four where not classed as under woodland at the first sampling. Three of these sites had planting dates prior to the first sampling so the land use classification at the time of original sampling must have been incorrect – or the trees had not grown enough to be distinguished from the "upland grazing" land use class which was assigned.

A similar analysis was carried out for the 32 sites in this rotation class to examine the effect of terrain condition on the rate of loss of carbon in those sites under first rotation. Table 12-6 shows that there was no significant difference between the terrain condition classes.(p>0.05).

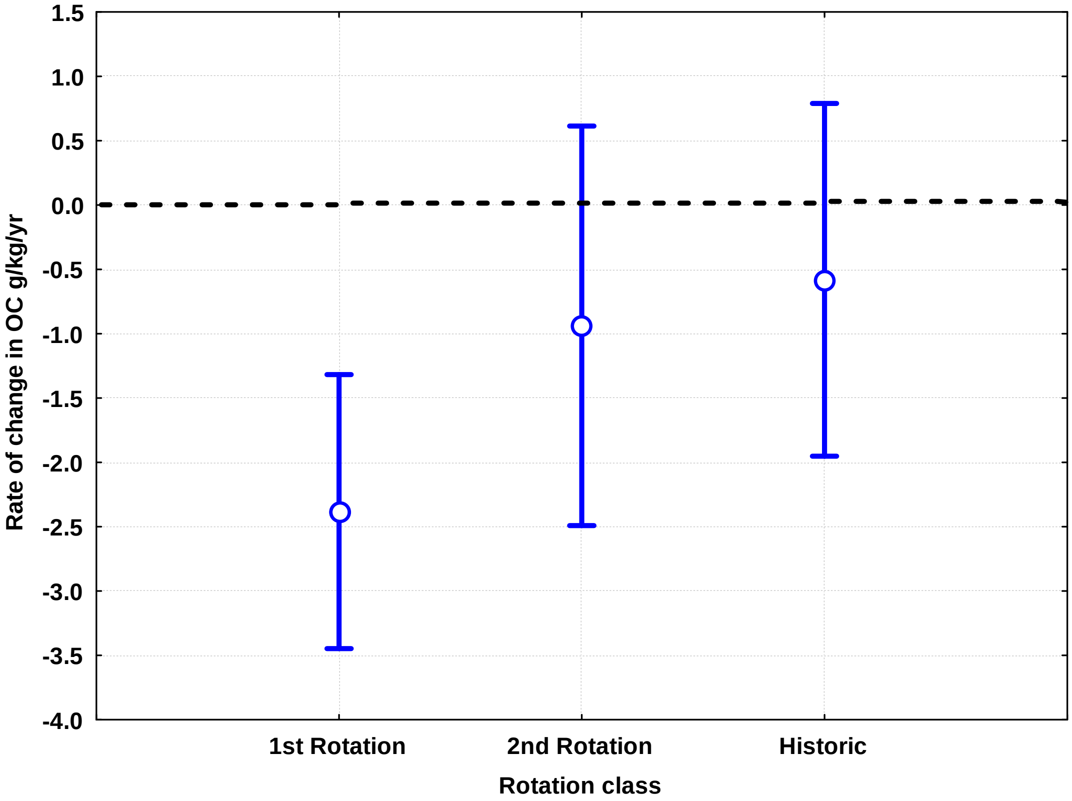

Figure 12-4 Rate of change of OC (g/kg/yr) adjusted to mean OC for rotation class

Table 12-11 ANOVA for all first rotation woodland

Effect	**SS**	**Degrees of freedom**	**MS**	**F**	**p**
Intercept	171.1108	1	171.1108	12.33518	0.001583
Terrain condition	80.3728	3	26.7909	1.93133	0.148325
Error	374.5379	27	13.8718		

An analysis of the year of planting showed there was no detectable relationship between the rate of change of OC and year of planting. The trees in their first rotation were planted between 1930 and 1976, those in their second or subsequent rotation were planted between 1970 and 2001 and the historic woodlands had planting between 1800 and 1998.

Statistical analysis of whole NSI dataset using models.

A parallel project funded by NERC (NE/D012848/1) has been carried out by Cranfield University and has made some progress investigating the observed change in OC using a simple model. This has given some insight into how much the climate would have had to have changed to give the changes observed in the NSI data and also how land use change could have contributed to the change. This project has also used the much more sophisticated model DAYCENT (a daily time step version of CENTURY, Parton et al 1987) applied across the whole of England and Wales on a 50km grid. DAYCENT estimates soil moisture and enables predictions of soil carbon change to be made based on daily weather data between the two samplings of the NSI sites. The model is also being run for a daily weather set from before the first sampling of the NSI sites. This will enable us to assess the size of the effect of the changing climate.

12.4 Discussion

The number of sites identified with land management information was small. This severely limited the second objective of this project which was to use the sites identified to develop quantitative relationships between the changes in soil carbon and climate, land management, soil and other variables. The results of the analyses that have been possible in this project and the parallel project are discussed in the context of existing literature to investigate the significance of the carbon changes for future policy requirements.

From the analysis of the NSI data using a simple model of soil carbon turnover it is clear that climate change cannot be solely responsible for the large losses of organic carbon from the soils of England and Wales. It was found that neither changes in rates of decomposition resulting from the effects of climate change on soil temperature and moisture, nor changes in carbon input from vegetation, could by themselves account for the overall trends (Kirk and Bellamy in review). It was also concluded that past changes (i.e. before the first sampling) in land use and management were probably dominant. This was confirmed by Smith et al. (2007) who estimated, based also on simple models, that only about 10 to 20% of the observed soil carbon losses in England and Wales could possibly be attributable to climate warming.

Burning on uplands

Both the sites which could be identified as having probably been burnt at some time between the two NSI samplings showed a decrease in soil organic carbon. Vegetation burning has been highlighted as one of the mechanisms for increased soil OC losses (Dawson and Smith 2006). Yallop et al. (2006) have shown that management burning in the English uplands is now widespread on Ericaceous moorland. In 2000, 17% of the area of this habitat had been burnt within the previous 4 years, equivalent to 114 km^{2}year^{-1} and the present median burn repeat time of consistently managed sites is approximately 20 years. They also found that within most of the English National Parks there has been a significant increase in the extent of new burns (from 15% to 30%) over the period 1980 to 2000.

Current burning guidelines (Defra 2007) indicate burning should avoid a range of sensitive mire habitats such as blanket bog, wet heath, raised bog and valley bog or mire. However the more extensive high carbon soil types including deep peats are not identified as ones to be avoided and this analysis suggests these may be the most vulnerable soils to carbon loss.

Arable land management

The fourteen sites investigated for this study highlight the complex nature of arable land management and how it changes over time. For example, the policy introduced in 1992 to ban straw burning did not immediately change the farming practices uniformly across England and Wales, some farmers changed immediately to incorporating straw whilst others delayed preferring to remove straw for a few years, and others tried incorporating straw then stopped. With the variety of arable crops available, including grass leys, it is not surprising that the variability of the rates of change of carbon for the arable NSI sites identified here do not allow the effect of a single management technique (incorporating straw) to be estimated. The extent of the interaction of all these variables is discussed in more detail by King et al. (2004).

One major change to arable systems generally was the conversion of grassland and natural vegetation to crops during and after the war (King et al. 2005). The main impact of this would have occurred in the decades before the first NSI sampling, but model calculations indicate there will have been some continuing changes in soil carbon in the period between the NSI samplings, perhaps accounting for up to 50% of the observed losses at arable sites (King et al. 2005). Other management changes in arable land include widespread improvements in land drainage (Robinson & Armstrong, 1988), greater use of mineral fertilizers (Defra, 2006), changes in crop types (King *et al*., 2005), and, in general, the adoption of more uniform management practices. These changes together will have tended to move soil carbon contents under arable systems towards a new, common steady state, consistent with the observed trends in the NSI data (Kirk and Bellamy in review).

Forest management

The analysis of the forest management data with the associated NSI sites has shown some significant losses of carbon under some management regimes. The analysis of the effects of the different rotations has shown that on average forests within their first rotation are losing soil organic carbon at the rate of about 2.4 g/kg/yr, about 70% more than those sites not in their first rotation. The effect of forest management on soil carbon sequestration has been reviewed by Jandl et al. (2007) who state that carbon loss can occur in a brief period following afforestation, when there is an imbalance between C loss by microbial respiration (due to disturbance) and C gain by litterfall. Although Jandl et al. (2007) do not say what a ‘brief’ period is, it appears that forests in their first rotation in this sample are still losing significant amounts of soil organic carbon over 20 years after establishment. This finding also agrees with the statistical analysis of all the resampled NSI data using simple models that shows that the loss of soil carbon could be reasonably explained by some change in land use at some time before the original sampling (Kirk and Bellamy in review).

12.5 Conclusions

This project has shown that there is a lack of detailed soil management information across all land uses and this has meant that the objectives of this project have only been met in part. From the limited range of management scenarios investigated in this project it is apparent that changes in management and variations of management within the broad land use categories assigned to the NSI sites have contributed to the loss of carbon reported in Bellamy et al (2005). It has not been possible to identify explicit factors directly leading to a loss in soil carbon but indications from the data in this project and recently published literature suggest that the factors which contribute the most to soil carbon loss are historic land use change and land management possibly explaining about 70-80% of the loss. We have shown in this project that the effect of planting trees on bare land has an effect on soil carbon for over twenty years – far longer than has been reported previously. It is clear that the effect of land use change and changes in land management can have long lasting effects on carbon in the soil. Any policy decision taken to try to stop the loss of carbon or to attempt to sequester carbon in the soil will need to be maintained over decades to be effective.

12.6 Reference

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13. Development and testing of coupled soil and vegetation carbon process model (WP 2.9 and 2.10)

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13.1 Introduction

The inventory currently uses simplified methods to calculate changes in soil and plant carbon in response to land use change. A long term aim has been to use process based models instead. There is currently no truly mechanistic model of soil carbon dynamics, as underlying processes are imperfectly known. However, several semi-mechanistic models of carbon turnover in plants and soil exist.

Carbon turnover models usually estimate plant and soil carbon based on climate, plant type and soil. Most of them are specifically for one land use type, such as agriculture or forest e.g. SUNDIAL, EPIC, DNDC, DAISY, YASSO (Williams, 1990; Hansen et al., 1993; Bradbury et al., 1993; Li, 2000; Liski et al., 2005). Often different models are used to assess carbon storage and changes for different land use types. This raises questions about the consistency of such assessments. Many assessments also ignore management and assume only natural vegetation e.g. LPJ and JULES (Cox et al., 1999; Sitch et al., 2003). However, land use change may be more important than climate change, at least in the short term (Betts et al., 2008).

The main purpose of this work package was to develop models for plant and soil carbon and evaluate their potential usefulness in carbon reporting. This has resulted in a new model, RothC-Biota as well as coupling a soil carbon model to the UK land surface model, JULES.

13.2 RothC-Biota carbon accounting tool

The model development was based on combining two models, one describing the aboveground component and the other describing the belowground component, and then developing it further from there. The aboveground component was based on BIOTA, originally a forest carbon model (Wang and Polglase, 1995; Milne and van Ojen, 2005). This component has later been extended to include grasses and crops.

RothC was used as the soil carbon model. As this model has been described elsewhere (Jenkinson et al., 1987; Coleman and Jenkinson, 1999), it is not further described here. The plant and soil carbon models are only coupled in that the plant model supplies the soil model with residues (“debris”). However, water holding capacity is taken as an input rather than calculated from clay content. This is done because independent estimates of water holding capacity are usually available, and better predictions can presumably be obtained with better input data.

Plant cover is described with land use types, which can be crops, grasslands or forest described by a certain parameter set that the user defines. At present parameter sets for cut and uncut grassland, conifer and deciduous forests, root crops and winter and spring cereals have been defined.

Plant GPP, respiration and NPP are calculated as described in (Wang and Polglase, 1995) with some modification. Assimilates are distributed into root, stem, branch and leaf according to allocation parameters for each land use type (Figure 13-1). Photosynthesis rate is determined by climatic factors, primarily radiation and temperature.

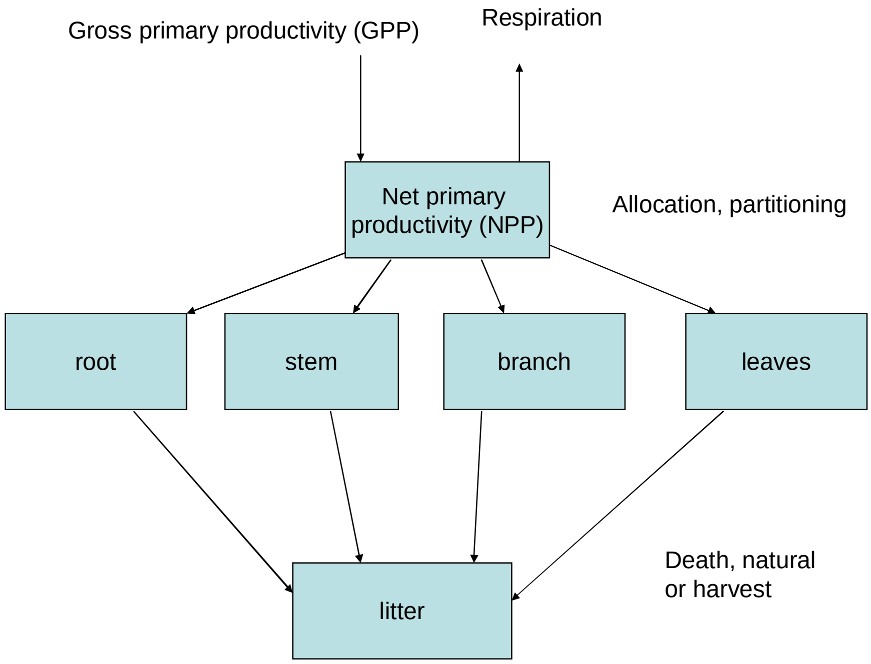

Figure 13-1: Carbon flow in Biota. Litter is taken as the plant input for RothC.

The amount of radiation the plant can use for photosynthesis is determined by how much of that radiation the plant can intercept. That depends on its leaf area index (LAI). In Biota LAI is calculated from the amount of leaf biomass at the time using the parameter specific leaf area. This parameter tells how much carbon there is per area of leaf.

Air humidity is used to determine stomatal opening and therefore limit photosynthetic rate. A simple factor for reducing plant productivity when water is limiting is included. This is based on the approach taken in the CENTURY model (Parton et al., 1992). Here, productivity is reduced when:

$$\frac{soilwater + rain}{PET} < 0.8$$

And productivity decreases as a linear function of this ratio below 0.8.

For each land use type the fraction of standing biomass that is returned to the soil in each month is input. There is one fraction for each pool (root, leaf, branch and stem). There are also allocation fractions, specifying the fraction of photosynthae that goes to each plant part in each month. For managed types there are also loss parameters for each harvest/management event as well as a fraction removed. Harvest means to totally remove and kill the plant, other events are cutting grass that removes some material, but do not kill the plant. For plants that that are not cut or harvested every year (trees), a different land use type can be specified for years with management events. The model can also simulate winter crops by adequately setting harvest and sowing days.

The model's plant production calculation has been tested for grassland in Scotland. Results can shows that the model's predictions are within range of measured values (Figure 13-2). Further testing for a larger scale is under way.

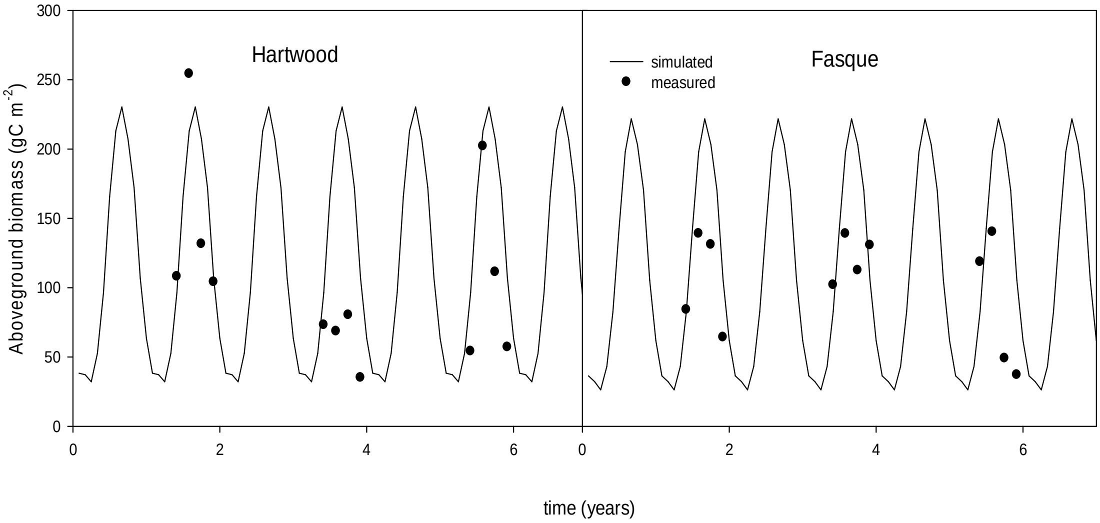

Figure 13-2: Model test on predicting aboveground biomass of uncut grass at two sites (Hartwood and Fasque) in Scotland **(Marriott et al., 2002)**.

13.3 JULES-ECOSSE land surface model

JULES has developed from the land surface scheme Hadley Centre general circulation model (Best, 2005). It has a well developed hydrology sub-model and at present much effort is put into developing the biological component of it through QUEST. In this model, plant cover is described using plant functional types (PFT's). These are vegetation types typical for wide biomes. At present there are 5 PFT's: Broadleaf- and coniferous trees, C_4 and C_3 grasses and shrubs. The model calculates the fraction of each PFT present based on competition and environmental factors (Best, 2005). There may be more PFTs added in the future. Each PFT is described using a set of parameters. The PFTs compete for resources and hence their mix and distribution is estimated within the model. As the main focus of the model is to investigate possible effects and feedbacks of global change, fluxes of carbon and water are described mechanistically as far as possible (Cox et al., 1999).

ECOSSE has been developed from SUNDIAL, a model developed to predict nitrogen turnover in agricultural systems (Bradbury et al., 1993). Changes include more soil layers and routines for DOC, methane, nitrous oxide and anaerobic decomposition though these capabilities are still undergoing development (Smith et al., 2007). The model has an aboveground component, but the above-ground component has so far only been developed to simulate arable crops. The soil C and N module of ECOSSE has been coupled to JULES. That is part of ongoing work of introducing a nitrogen cycle to JULES. It also means that soil carbon is now calculated using a multi-compartment model as opposed to simple one compartment model as before. This is more realistic and has been shown to have some impact on the predictions of the effect of climate change on soil carbon (Jones et al., 2005).

The output of the coupled model has been compared to outputs from JULES without ECOSSE where possible. Figure 13-3 shows the comparison for soil carbon. The overall trend in the changes is the same using both soil models, as it is mainly influenced by the effect of climate and atmospheric CO_2 on plant productivity and soil decomposition rate.

The ECOSSE model has been applied in Scotland and Wales using inventory data on soils and land use change to drive the model, sowing proof of concept for use in AFOLU inventories. There is good agreement between ECOSSE and current inventory methods in estimates of changes in soil carbon due to land use change (see figures 13-3 and 13-4).

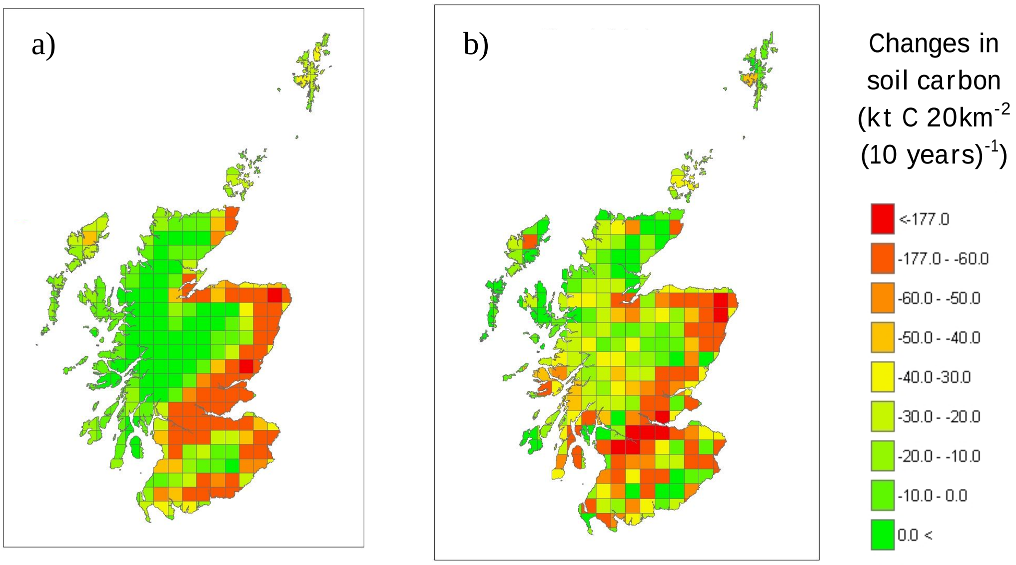

Figure 13-3: Maps showing Comparison of estimates of total change in SOC stock in Scotland 2000-2009 using current inventory method (a) and the ECOSSE model (b) - (from Smith et al., 2009)

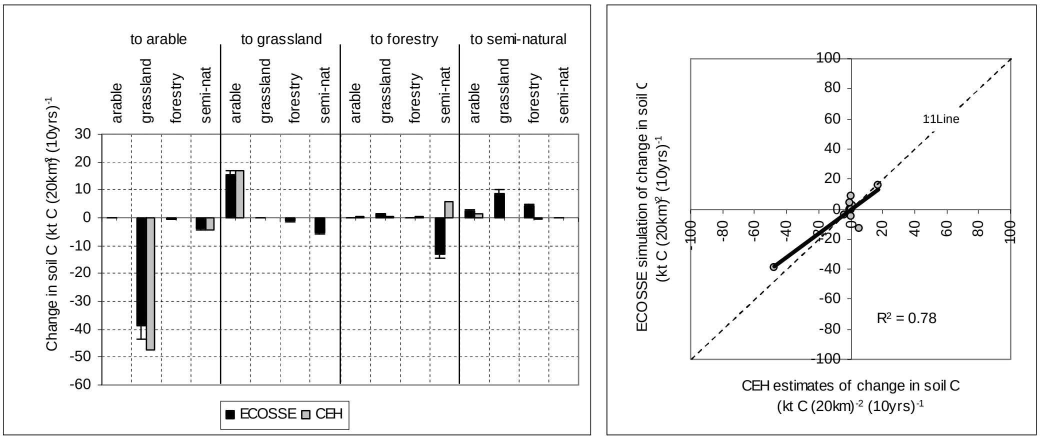

Figure 13-4: Bar charts and regression showing comparison of estimates of total change in SOC stock in Scotland 2000-2009 using the current inventory method (a) and the ECOSSE model (from Smith et al., 2009)

13.4 Further plans

RothC-Biota’s predictions for GPP and NPP will be compared to values derived from MODIS satellite data for Scotland. This will give a better idea on how well the model performs on a larger scale (work underway).

A COST63 action short term scientific mission will compare several models on common data sets to come up with a recommendation for a process based model to use for soil carbon reporting in forests.

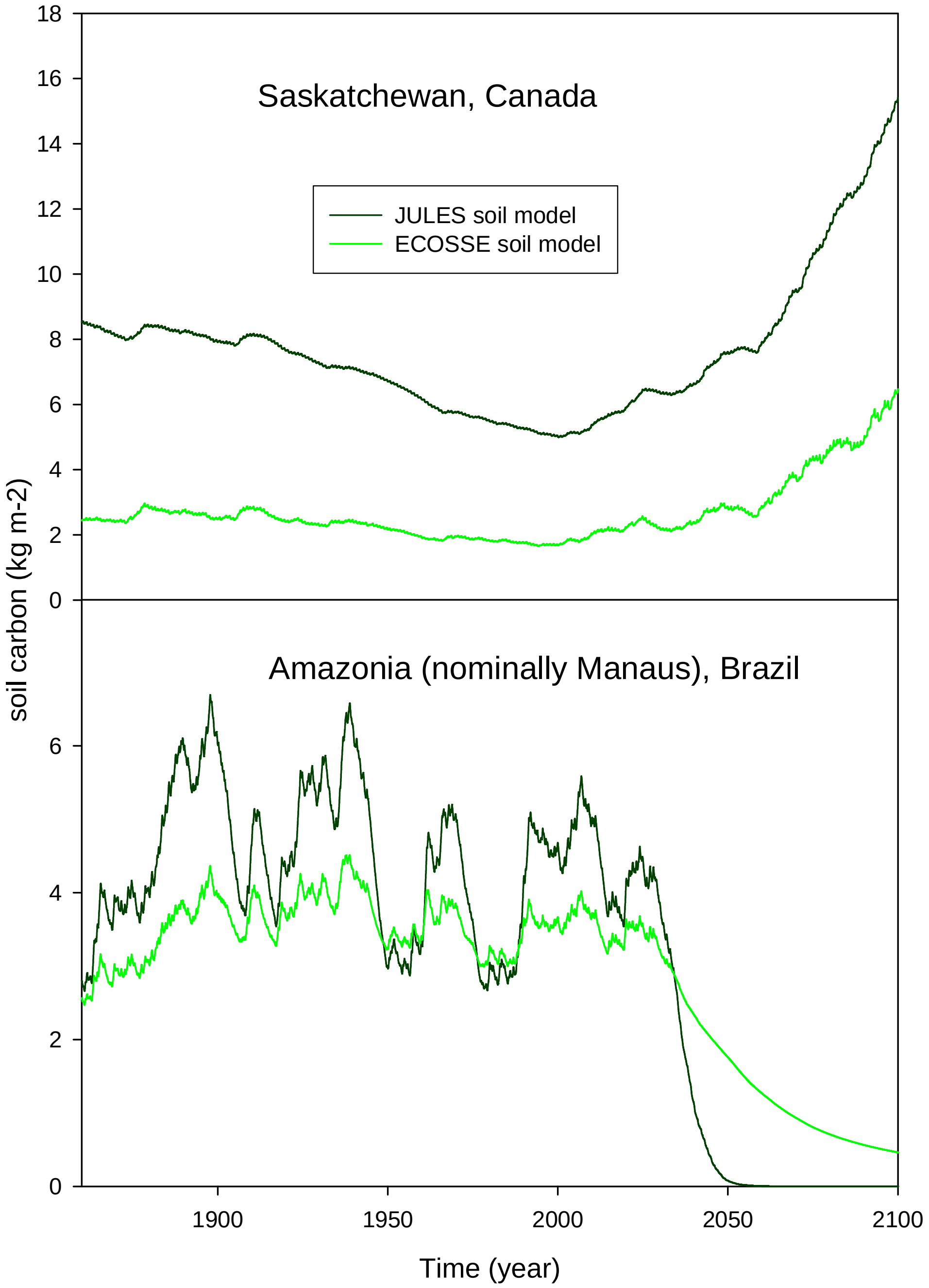

Figure 13-5: Soil carbon as calculated by JULES soil model and with ECOSSE soil model within JULES for two sites using climate data from the Hadley Centre GCM prediction.

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14. Modelling the impact of climate, CO_2, and land use change on the carbon balance of terrestrial ecosystems in Great Britain (WP 2.11)

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14.1 Introduction

The impact of environmental changes (in climate, CO_2 and nitrogen deposition) upon LULUCF carbon fluxes has not been considered in previous UK inventories. However, recent research has shown that carbon sinks in European forests have been affected by 20th century changes in climate, atmospheric CO_2 and nitrogen deposition, and that changes in these environmental drivers will continue to affect carbon budgets (van Oijen et al., 2004). Currently, the models used in the inventory are empirical, based on static relationships describing (i) forest growth over time, and (ii) soil carbon changes over time following land use change. Especially when projecting LULUCF fluxes into the future, there is a need to demonstrate that the existing models remain reasonable, or to account for effects of environmental change where they interact with LULUCF fluxes. For example, if climate change were predicted to substantially reduce the carbon sink arising from afforestation, the projections based on past growth data would have to be revised accordingly.

Under the Kyoto protocol, the offsetting of fossil fuel emissions must result from management actions that have lead directly to carbon sequestration, and not include sinks that have resulted indirectly from anthropogenic activity, such as CO_2 fertilisation of existing forests. The Marrakesh Accord brought in the need to distinguish 'direct human-induced' and 'indirect' components of any sink (Schulze et al., 2002). In order to accredit directly human-induced sinks, there is a need to factor out effects of climate change, CO_2 fertilization and nitrogen deposition, and effects due to past management practices and age structure in forests prior to 1990. However, there is no generally accepted mechanism for doing so. As reporting for the Kyoto commitment period approaches, this issue becomes increasingly important, especially where inventories are based on national-scale measurements of forest annual volume increments and soil carbon (the UK is unusual in basing its inventory on modelled growth data).

Here, we demonstrate a procedure for quantifying the effects of environmental change on carbon fluxes arising from LULUCF, and which can factor out direct and indirect components of the net sink. The procedure uses a mechanistic model which represents the processes which are affected by these environmental changes (principally photosynthesis, respiration, plant growth and decomposition), and that includes the effects of land use change and land management. Here, we apply the model to the UK at a 20 km grid scale, to estimate the total flux and the components attributable to direct and indirect factors. Using the model, we perform simulations to provide a complete factorial experiment ie. with and without changes in climate, atmospheric CO_2 and land use, and all permutations. By analogy with classical analysis of variance (ANOVA), we calculate the effect of these factors on LULUCF carbon fluxes from the interaction terms (climate x land use etc.). 'Factoring out' the effects of climate and CO_2 from the total flux is obtained simply from the differences between simulations with and without factors (the ‘main effects’, in ANOVA terminology).

A recent survey which resampled soils across England and Wales showed an apparent net emission of carbon, at the rate of 0.6% yr^{-1} over the time period 1978-2003 (Bellamy et al., 2005). This flux was found to be irrespective of land use at the sites sampled and Bellamy et al. (2005) inferred climate change to be an influencing factor in the observed carbon loss. If correct, this phenomenon requires accounting for in the UK inventory, and the mechanism understood. A further role of the work here was to compare the results of Bellamy et al. (2005) with process-based modelling results, and to estimate the likely contribution of climate, CO_2 and land use to the observed change.

14.2 Methods

HyLand Model

A process-based model, HyLand (Levy et al., 2004a; 2004b), was used in this study. The model was originally developed to predict the impact of future climate change on global vegetation, based on the Hybrid model of Friend et al. (1997), with adaptations to allow the transient effects of land use change on vegetation and soil carbon stocks to be simulated. Processes represented in the HyLand model include plant competition, photosynthesis, plant respiration, carbon allocation and decomposition (for a full model description see Friend et al. (1997) and for HyLand adaptations see (Levy et al., 2004a; 2004b). Nitrogen dynamics were not included, and foliage was given a prescribed N value (Levy et al., 2004a), but this will be re-instated in future work. The model requires inputs of atmospheric CO_2 concentration, land use change and climate variables. The exchange of carbon, and water between the soil and atmosphere was simulated using a daily time-step. Vegetation was represented as three generic plant functional types (PFTs): needle-leaved trees, broad-leaved trees, and herbaceous plants. The carbon content of the three PFTs and soil varies dynamically with the climate and atmospheric CO_2 concentration. Five land use types were represented: natural, forest, pasture, arable, and urban, which were assumed to influence carbon fluxes as follows.

Natural vegetation. Where natural vegetation was present, no constraints were placed on the simulated vegetation, and the proportion of each PFT was resolved by competition.

Deforested (one year following transition from forest to any other type). (i) It was assumed that 64% of the above-ground stem carbon was removed instantly. (ii) Clear-cutting was immediately followed by a fire, which oxidized 30 % of coarse above-ground stem litter, all other litter, and all above-ground herbaceous plant parts (Hao et al., 1990). (iii) The remaining litter was apportioned to coarse and fine litter above- and below-ground. (iv) Soil disturbance in the year of deforestation was assumed to cause 30% of the carbon in protected pools to move to the active decomposable pools.

Cropland. (i) Tree regeneration was prevented. (ii) Cultivation caused 30% of the carbon in protected pools to move to the active decomposable pools every year. (iii) Harvesting removed 50 % of above-ground vegetation carbon every year. The remaining carbon was transferred to litter. (iv) Incorporation of litter was simulated by assuming that 50 % of the above-ground structural and metabolic litter pools were transferred to the topsoil structural and metabolic litter pools each year of cultivation (van Veen and Kuikman, 1990; Voroney and Angers, 1995).

Grassland. (i) Tree regeneration was prevented. (ii) Grazing removed a fraction of the above-ground vegetation every day, equivalent to 50 % of daily NPP.

Urban (i) Tree regeneration was prevented.

The generic parameterisation used in global simulations was used as a default starting point. The model was then calibrated to give the present-day mean soil carbon values for grassland and arable land use types in the UK, according to Bradley et al. (2005).

Land use change data

Land use change matrices were calculated for England, Scotland and Wales at a 20km grid scale using two data sources: (i) the Countryside Surveys (CS) of 1984, 1990 and 1998 (Haines-Young et al., 2000), which surveyed 1km x 1km squares across the UK, and (ii) Monitoring Landscape Change data from 1947, 1969 and 1980 (MLC, 1986), which assessed land use change using aerial photography (Table 14-1). Land use classes from these surveys were mapped on to those used described above, based on the Good Practice Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) (IPCC, 2003).

Table 14-1. Source of land use change data for Great Britain used as input to the HyLand model (From Milne and Mobbs, 2006).

Period	Method	Change matrix data
1950-1979	Measured Land Use Change Matrix	MLC 1947 – MLC1980
1980-1983	Interpolated	CS1984 – CS1990
1984-1989	Measured Land Use Change Matrix	CS1984 – CS1990
1990-1998	Measured Land Use Change Matrix	CS1990 – CS1998
1999-2020	Extrapolated	CS1990 – CS1998

Areas of unchanged land were obtained from the CS for the 1980s and 1990s. Using these data and the changes in previous decades from the MLC data, unchanged areas were calculated back to the 1950s. This was repeated for projections, assuming rates of land use change remained constant from the present day to the 2020s.

These data were used as input to the HyLand model. The model was run on a 20 km scale grid covering Great Britain (comparable land use data were not available for Northern Ireland), using the estimated matrix of land use change for each grid cell.

Climate data

The Climate Research Unit (CRU) TS 1.2 dataset was used. This provides data for the United Kingdom at 10 minute spatial resolution, including cloud cover, temperature, precipitation and vapour pressure (Mitchell et al., 2004). These data comprise interpolated observations for the period 1901-2000, and projections from 2001-2100 based on the SRES scenarios (IPCC, 2000). Four SRES scenarios were used to examine the range of effects of possible future climate change. For the factorial simulations, the B2 scenario was used, representing a medium-low future emissions scenario with an increase in global temperature of 2.3 °C by 2100 (Hulme et al., 2002).

CO_2 concentration data

Data for atmospheric CO_2 levels were taken from the ISAM model (IPCC, 2001). Future concentrations were based on the SRES scenarios. For the factorial simulations, the B2 scenario was used, in which CO_2 levels reach 411 ppm by 2020 (Table 14-2).

Simulations

A 'spin-up' to equilibrium conditions was carried out for 1000 years. Pre-industrial CO_2 concentrations and climate were used, and land use was set to natural for all plots. Over this time the model state variables reached equilibrium, which were then used as the start values for the historical simulations. The change between complete natural cover and the first recorded state of land use (in 1950) was assumed to be linear, with transitions randomised between 0001 and 1950. The one exception was changes to urban, which were only introduced in the 20th century. The historical data for CO_2 and climate were used from 1860 onwards.

For the time period 1990 to 2100, a full set of factorial simulations was performed, with all permutations of CO_2, climate and land use change. The input factors were either varied according to the data sources described above, or held at their 1990 values until 2100 (Table 14-3).

Table 14-2. Source of input variables for climate, CO_2 (ppm) and land use (LU). [a]Changes from natural to 1950 state assigned randomly between 0001 and 1949.

	Input		
Time Period	Climate	CO_2	LU
'Spin-up'	Pre-industrial (HadCM3 1860)	286	Pre-industrial (set to natural)
0001-1859	Pre-industrial (HadCM3 1860)	286	Interpolated[a]
1860-1949	CRU TS 1.2	286-311	Interpolated[a]
1950-1989	CRU TS 1.2	311-350	MLC 1947- CS 1990
1990-2100	CRU TS 1.2 B2 Scenario	351-411	CS1990-CS1998

Table 14-3. Full factorial design and source of input variables for climate, CO_2 (ppm) and land use (LU).

	Input		
Simulation	Climate	CO_2	LU
All factors	CRU TS 1.2 B2 Scenario	337-411	CS1990-CS1998
Climate change only	CRU TS 1.2 B2 Scenario	336	CS 1990
CO_2 change only	CRU TS 1.2^c - B2	337-411	CS 1990
LU change only	CRU TS 1.2^c - B2	336	CS1990-CS1998
Climate and CO_2 change	CRU TS 1.2 B2 Scenario	337-411	CS 1990
Climate and LU change	CRU TS 1.2 B2 Scenario	336	CS1990-CS1998
CO_2 and LU change	CRU TS 1.2^c - B2	337-411	CS1990-CS1998
No factors change	CRU TS 1.2^c - B2	336	CS 1990

14.3 Results

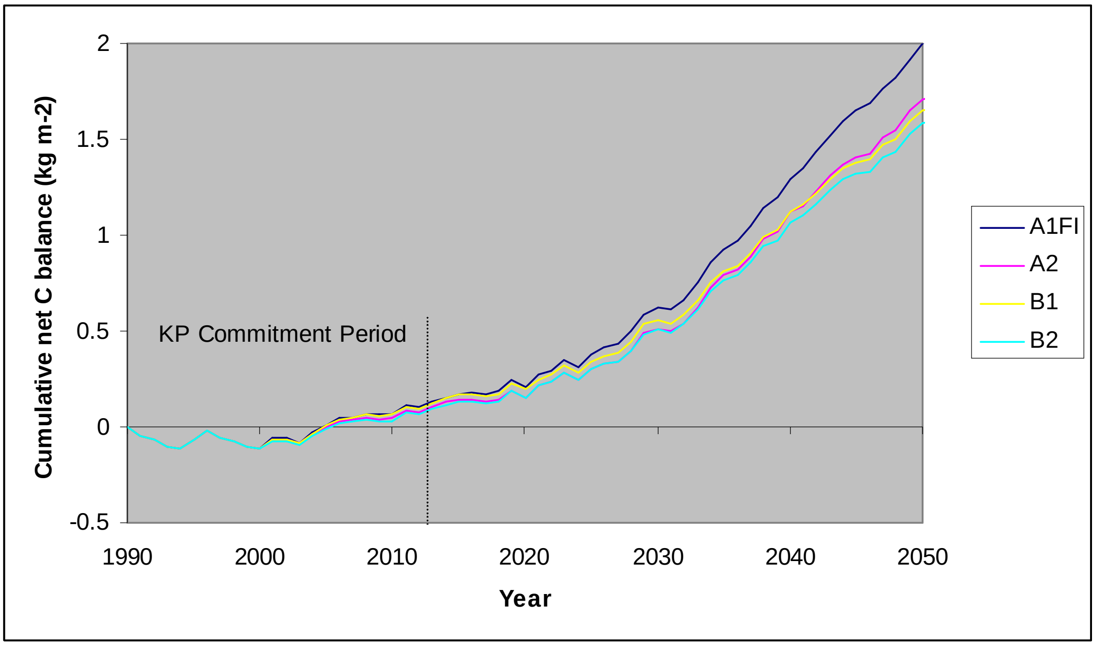

Figure 14-1. Cumulative net carbon balance of terrestrial ecosystems (including land use change fluxes) in Great Britain predicted by Hyland between 1990 and 2050, using four SRES climate scenarios. Positive fluxes indicate uptake by the land surface.

Figure 14-1 shows the net change in the carbon balance of GB terrestrial ecosystems, including land use change fluxes (‘net biome productivity’ in IGBP terminology). This shows that GB ecosystems are predicted to provide a net sink for carbon from around the present day onwards, and give a cumulative sink of 0.062 kg C m^{-2} over the Kyoto Protocol commitment period. This sink continues over much of the century, irrespective of climate change scenario.

Results from the factorial analysis are shown in Figure 14-2 and Figure 14-3. In the control run, where there is no further change in the input variables after 1990, carbon continues to accumulate in terrestrial ecosystems until 2100 and beyond, although the increase is asymptotic. This is because the model has been perturbed from equilibrium by the changes in the previous centuries (increased CO_2, warming and afforestation), and takes a long time to reach a steady state, particularly in the slowly decomposing soil carbon pools. To quantify the effect of the factors, we need to compare them against this background of continuing change in the control run. Figure 14-2 shows that the net carbon source between 1990 and 2006 is a result of both climate change and land use change, with the former roughly twice as important. As the century progresses, the

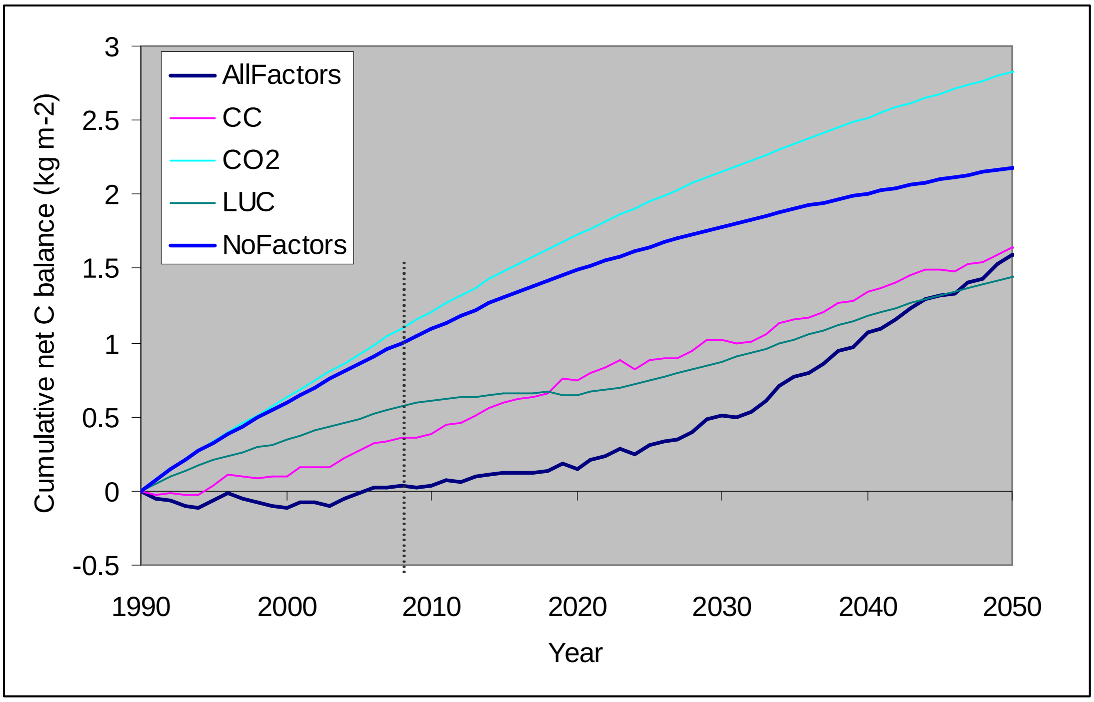

Figure 14-2. Cumulative net carbon balance of terrestrial ecosystems (including land use change fluxes) in Great Britain predicted by Hyland between 1990 and 2050, in a sub-set of the factorial simulations (see Table 3). Positive fluxes indicate uptake by the land surface.

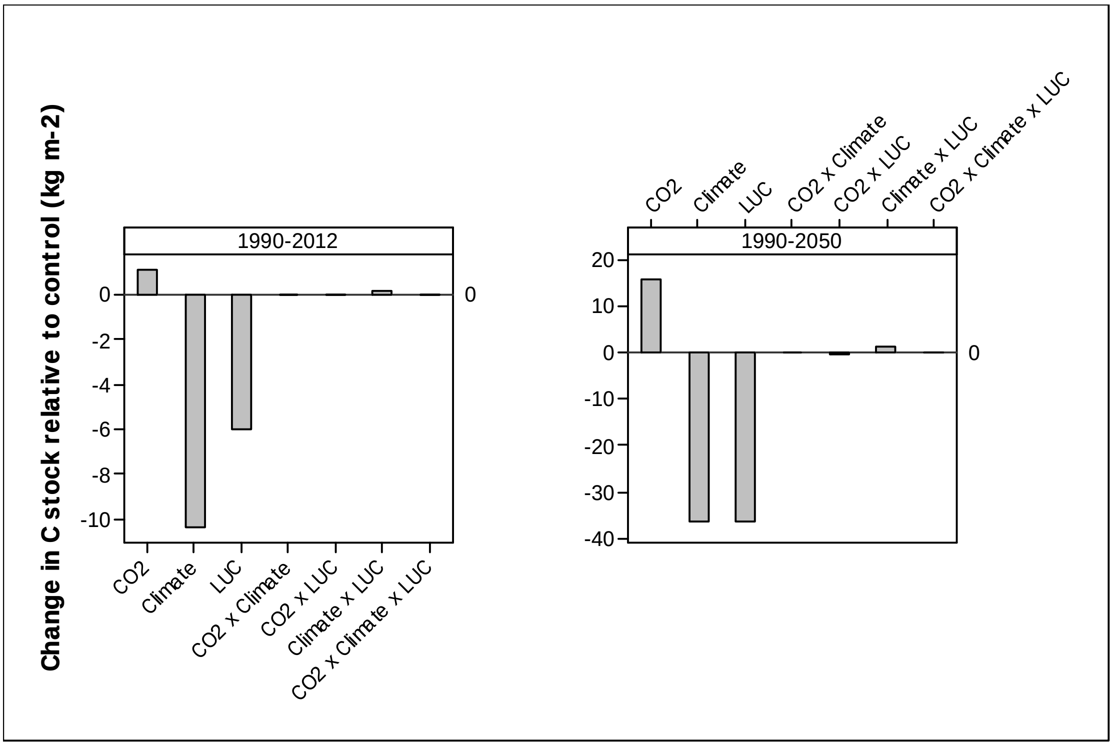

Figure 14-3. Factorial analysis, showing main effects and interactions of the three factors on the net change in the carbon balance of terrestrial ecosystems in Great Britain, relative to the control simulation where all inputs are held constant at their 1990 values. Results are shown for two time periods: the Kyoto Protocol Commitment Period (1990-2012) and 1990 to 2050. Positive fluxes indicate uptake by the land surface.

magnitude of the CO_2 effect increases linearly, whilst the effects of climate and land use stay more or less constant. This causes the net sink, when all factors are included, to grow over time, from a small value over the Kyoto Protocol Commitment Period, to a substantial sink between 1990 and 2050. Whilst the effect of CO_2 is relatively straightforward, the response to climate change is itself the result of a balance between increased soil respiration with warming, increased photosynthesis with warmer temperatures, and a variable effect of soil moisture on both of these, with the first of these predominant. Land use change may also act as a source or a sink, but the net effect in the 1990s was to produce a source of CO_2 (through transitions to arable and urban), and this was assumed to continue over the next century.

Table 14-3 presents the factorial analysis over the Kyoto Protocol Commitment Period (1990-2012) and 1990 to 2050. The pattern is rather similar in both periods, with CO_2 as the sole positive effect, and climate and land use both having negative effects. The effects of CO_2 and land use change are larger in the second period. Of most interest here is the magnitude of the interaction terms. One of our aims was to identify whether the carbon fluxes arising from land use change are affected by CO_2 and climate change, or whether the effects are simply additive, and can be considered in isolation. Table 14-3 shows that the interactions are small, and the latter is a reasonable approximation over these time periods.

The model predicts a very small net decrease in soil carbon over the period 1978-2003 of 0.16 kg C m^{-2} or 0.03 % (Figure 14-4). This is twenty times smaller than the rate of decrease of 0.6 % found by Bellamy et al. (2005). The model also predicts a small increase in the vegetation carbon stock, and the change in total ecosystem carbon is only -0.05 kg C m^{-2}. Comparing the spatial distribution of change (Figure 14-5) with that of Bellamy et al. (2005), there is little correspondence between the two. Bellamy et al. (2005) find the pattern follows that of carbon content, such that the losses are greatest from organic soils in Wales and the Pennines. Our distribution follows more closely that of the land use change data, which do not show an obvious pattern.

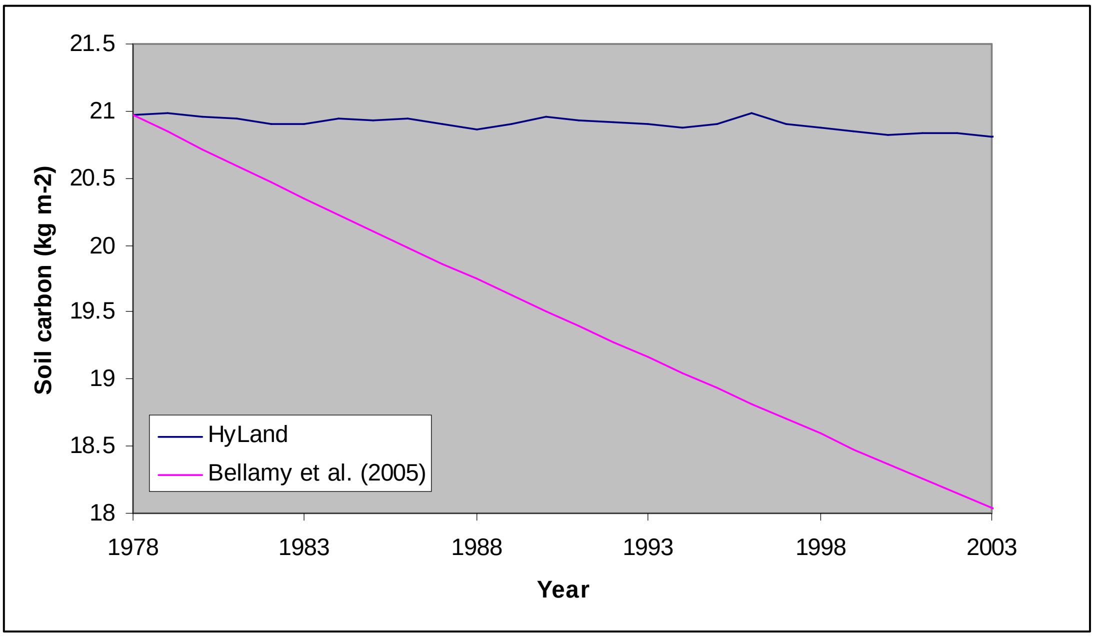

Figure 14-4. Mean soil carbon in Great Britain between 1978 and 2003 predicted by Hyland, in comparison with the relative trend measured by Bellamy et al. (2005), assuming the same initial soil carbon content.

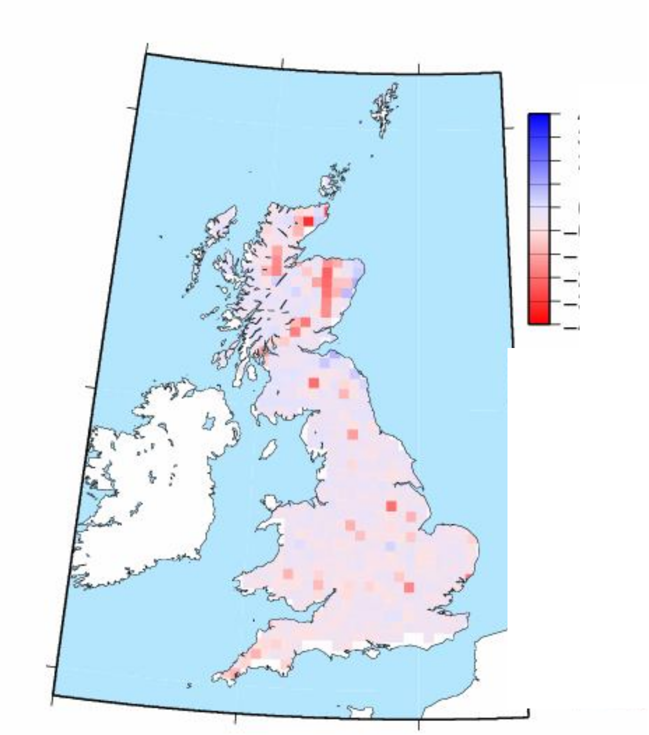

Figure 14-5. Spatial distribtution of the change in soil carbon (kg m^{-2}) between 1990 and 2005 predicted by HyLand. Red = source, blue = sink.

14.4 Discussion

By analogy with classical analysis of variance (ANOVA), we calculate the effect of environmental factors on LULUCF carbon fluxes from the interaction terms (climate x land use etc.). The results here show that these interactions are small compared to the main effects, indicating that the effects are mostly additive. The present inventory method is thus not unreasonable in ignoring these effects. It is conceivable that these interaction terms could be larger over different time periods or in different countries, so some caution is needed in generalising these results.

A procedure for 'factoring out' the effects of climate and CO_2 from the total flux is demonstrated, using simply the differences between simulations with and without factors (the ‘main effects’, in ANOVA terminology). The results show that climate change and CO_2 are significant terms which would need to be factored out to obtain the directly-human-induced components of the net sink, though their effects tend to counter-balance each other. Land use change is predicted to be a overall source of carbon after 1990, but this is based on continued use of 1990s Countryside Survey data, and more sophisticated techniques for projecting trends in land use change forwards could be developed (e.g. Rounsevell et al., 2006).

The procedure relies on the assumptions within the model being sound, or at least generally acceptable, given the current state of knowledge. Use of multiple models would provide some quantification of the range of possible outcomes where opinions differ over underlying processes. For example, the long-term response of plants to elevated CO_2 is still contentious despite years of research (Caspersen et al., 2000; Oren et al., 2001), and down-regulation of photosynthesis might largely negate any short-term gains. A range of model structures might be chosen to reflect this. A less obvious source of uncertainty is in accounting properly for legacy effects due to environmental or land use changes before the time period in question. As shown in Figure 14-2, changes in carbon stocks continue, and indeed are larger, in the control run where inputs are held at their 1990 values. For example, carbon sequestration by forests continues long after the year of afforestation. The historical time course of input data prior to 1990, which have perturbed the model from equilibrium, need to be correct if this is to form the control against which changes in the commitment period are judged. In these simulations, when CO_2 and climate were kept constant, they were held at their 1990 values. However, using a decadal mean (or weighted average) would mean that there was less chance of a single, possibly atypical, year influencing the control run disproportionately.

The work here can be improved in a number of ways. Here, future climate is based on a single climate model (HadCM3), and the factorial analysis is based solely on the B2 scenario. A more complete analysis would include multiple climate models, multiple scenarios, and multiple ecosystem models, and this may be feasible within the project. The land use change matrix used here was based only on Countryside Survey and Monitoring Landscape Change data. Forestry components of the LULUCF inventory use Forestry Commission afforestation data, which is a source of disparity with our results. Further work is needed to integrate these data sources into a single, internally consistent, set of land use change matrices at 20-km scale. Issues of quality, classification and sampling error in the land use change data are probably the largest sources of uncertainty in the LULUCF inventory as a whole. A further Countryside Surveys was carried out in 2007, with data due to become available soon. The extension of this dataset will be included in future simulations and could potentially substantially change the results found here.

The rates of change predicted by HyLand are much lower than those measured by Bellamy et al. (2005) who estimate annual losses of carbon from soils across England and Wales to be in the range of 0.6% year^{-1}. Here, we predict losses to be 0.03 % year^{-1}, ie. twenty times less. Bellamy et al. (2005) also show these values to be irrespective of land use change and suggest climate change as a causal factor.

Our simulations implicate both land use change and climate change as source terms of approximately similar magnitude in the near-present day carbon balance, but at rates much smaller than Bellamy et al. (2005) suggest. Other soil re-sampling studies find rather different results to Bellamy et al. (2005), and it is possible that there are issues over interpretation or statistical artefact in the result of Bellamy et al. (2005) (Smith et al. 2007). Kirkby et al. (2005) predicted a small increase in soil carbon over the 30 year period 1971-2000 of ~0.01% year^{-1} in a topsoil study of British woodland. Chamberlain et al. (submitted) found a small increase in UK soils from Countryside Surveys in recent decades.

Nitrogen deposition is not currently represented dynamically in Hyland, and could potentially provide a method for soil carbon accumulation through its positive impact on vegetative growth. Future simulations are planned in which nitrogen dynamics will be included. However, this also remains a contentious area, as to the extent of the effect of enhanced nitrogen deposition on forest carbon sequestration (Magnani et al., 2007; Sutton et al., 2008) and this would add a further dimension of uncertainty.

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14.6 Appendices

Appendix 1. Relationship between land categories of Countryside Surveys (CS) and IPCC-LULUCF Guidance.

Forest	Cropland	Natural	Urban	Pasture
Broadleaved/mixed	Arable	Neutral grassland	Built up areas	Improved grassland
Coniferous	Horticulture	Calcareous grassland	Gardens	
		Acid grassland		
		Bracken		
		Dwarf shrub heath		
		Montane		
		Supra littoral sediment		

Appendix 2. Relationship between land categories of MLC and IPCC-LULUCF Guidance.

Forest	Cropland	Natural	Urban	Pasture
Broadleaved wood	Crops	Upland heath	Built up	Upland smooth grass
Conifer wood	Market garden	Upland coarse grass	Urban open	Improved grassland
Mixed wood		Gorse	Transport	Rough pasture
Orchards		Bracken	Mineral workings	Neglected grassland
		Lowland rough grass	Derelict	
		Lowland heather		

15. Consideration of options for monitoring and accounting for carbon in harvested wood products in the UK (WP 2.12)

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15.1 Introduction

Progress has been achieved in clarifying the options for monitoring carbon stocks, sinks and sources in harvested wood products (HWP) in the United Kingdom and, in principle, by other countries. The basis of any monitoring method needs to be informed by the fundamental dynamics of HWP carbon, which are outlined in this report.

Two main monitoring methodologies can be identified:

- Direct inventory.
- Model-based monitoring.

An outline description of these methodologies is given and the implications for making implementation in the UK are discussed, notably in terms of data availability and the capacity to support the main HWP carbon accounting methods currently under consideration in international negotiations:

- Production
- Simple decay
- Stock Change
- Stock change (constrained to transactions among Annex 1 countries)
- Atmospheric Flow.

As appropriate, a description is given on the key options for implementation of these methods based on available data and techniques.

15.2 Basic dynamics of HWP carbon

Carbon is removed from the atmosphere during tree growth and dry wood is approximately one half carbon by weight. A proportion of this carbon is released back to the atmosphere as foliage, small branches and fine roots die and decompose, but the rest remains in larger roots, branches and stemwood. Some of this wood, and the carbon within it, can be harvested and turned into useful products. Carbon remains 'fixed' within these products throughout their useful lifespan and is only released back to the atmosphere if the wood is oxidised as a result of combustion or decomposition.

Humans influence the quantities of carbon contained in forests and wood products by:

- Removing carbon from the forest to make wood products;
- Redistributing carbon within the forest system (e.g. leaving some parts of harvested trees on the forest floor);
- Altering the dynamics of carbon exchange between the atmosphere and the living forest (e.g. the trees left standing after harvest may grow differently because competing trees have been removed);
- Disposing of wood products at the end of their useful lives.

Harvested wood is used to make what may be referred to as primary products. When primary products come to the end of their useful lives, the wood may be reused in secondary products. Both primary and secondary wood products make a contribution to carbon dynamics.

15.3 Carbon in primary wood products

The main processes that determine the carbon dynamics of harvested wood products are fundamentally different to those at work in forest ecosystems. The carbon content of the forest ecosystem depends on the balance between the process of photosynthesis and respiration by trees, the accumulation and loss of organic matter in soil, disturbances such as forest fires and windthrow, and interventions by humans (tree planting, thinning and deforestation). Most of these processes are biophysical. In contrast, C stocks and flows associated with wood products depend first and foremost on socio-economic forces.

As explained in Appendix 1, the size of a particular wood product pool is a direct consequence of the number of units of the product in use at a given time and the average amount of wood contained in individual units of the product. The patterns in utilisation of wood by humans are thus the main driver of wood product carbon dynamics although, ultimately, this is limited by the potential for forest areas to produce timber to meet requirements.

The dynamics of wood product C suggest that the potential for sequestration is limited – because people can only find use for so many products. However, there may be some scope for increasing the quantity of wood in individual units of a product. For example, modern house designs often involve relatively small amounts of structural wood, so by changing designs, the quantity of wood contained in a house could be increased.

It should also be noted that, as with trees, carbon sequestration in wood products is potentially reversible. If existing or new wood products are replaced with non-wood products at some point in the future, C stocks in wood products will decrease, with implied emissions of carbon to the atmosphere, if wood products taken out of use are burned or decay.

Carbon in secondary wood: bury, recycle or burn?

When people finish with a wood product, it can be buried in a landfill, recycled into a secondary product, or burned. These three options have different positive and negative carbon balance impacts. The impacts on carbon dynamics are summarised in Table 15-1.

Table 15-1. Carbon impacts of landfilling, recycling and incinerating wood

Impacts	*Landfilling*	*Recycling*	*Incineration*
15.3.1..1.1 ositive	• Carbon in wood is stockpiled underground, rather than released to the atmosphere at once. The time taken for landfill wood and paper to decompose can be very long. • Methane released by decaying landfill material could be trapped and used for energy.	• The time for which carbon is retained out of the atmosphere is extended through reuse of wood in secondary products. • Recycling may reduce the requirement for virgin wood. secondary products could be used in place of non-renewable materials.	• Burning wood products at the end of their service life could be used to provide heat or generate electricity. • Wood ash could be returned to forests as a source of nutrients, although there are pH issues.
Negative	• Decaying wood may release methane, which is a strong greenhouse gas.	• Recycling process require energy and sometimes chemicals.	• Materials need to be sorted carefully to avoid contamination. Energy may be needed for this. • Burning needs to be efficient to ensure that carbon is released as CO_2, not as more complex carbon compounds. • Carbon locked in wood is released back to the atmosphere.
	• All three options require transport of wood which requires energy.		

Of the three options, the carbon dynamics of 'fixed' carbon are most simple for burning wood: carbon fixed in wood is released back to the atmosphere immediately. The mix of carbon-based gases released depends on how efficiently the wood is burned. If this is efficient, most of the carbon returns as CO_2. For less efficient cases (e.g. poorly tended open log fires), a proportion is returned as more complex hydrocarbons. The carbon dynamics of recycled wood products are similar to primary products - the main determining factor is the requirement for the particular product being manufactured. However, there is no clear picture about the interactions in consumption of virgin and recycled wood. Quite high uncertainty also surrounds the carbon dynamics of landfilled wood. The quantity of carbon in wood in landfill could be significant, but estimates are based on many assumptions and it is not clear if, when or by what process landfilled wood will decay.

Methodologies for monitoring HWP carbon

Essentially there are two classes of methodology for estimating stocks and flows of carbon associated with HWP:

- Inventory-based methodologies
- Model-based methodologies.

Inventory-based methodologies

The technical approaches to the inventory of carbon stocks in HWP have been the subject of investigations by Pingoud (1996, 2000) and Alexander (1997). The general technique involves:

- Stratifying HWP into specific categories
- Attempting to directly estimate the carbon stock in each HWP category.

For example, Alexander (1997) defined the following categories of HWP:

- Structural timber in domestic buildings
- Structural timber in commercial buildings
- Non-structural timber in domestic buildings (e.g. furniture, utensils, books)
- Non-structural timber in commercial buildings
- Timber in fencing and sheds
- Mining timber
- Railway sleepers
- Transmission poles
- Palletwood and packaging
- HWP in landfill.

Where possible, an attempt was then made to estimate the carbon stock in each of these categories (for a base year of 1990) by direct measurement and/or application of relevant statistics. To take the case of structural timber in domestic buildings (Figure 1), this involved combining statistics on the housing stock in England, Wales, Scotland and Northern Ireland with measures from the construction industry for the amount of structural timber in different types of domestic building and estimates of the dry matter and carbon content of wood. Values for all of these quantities were reasonably easy to obtain but this was not the case for most of the HWP categories – in these instances Alexander resorted to model-based methodologies.

The study of Alexander (1997) was useful in demonstrating that the bulk of carbon stocks in HWP were contained in relatively few categories, the most important being structural timber, non-structural timber in buildings and landfill. It also revealed that a fully inventory-based approach would be impossible with data currently available in the UK. Although surveys could be designed to estimate carbon stocks in each of the HWP categories, these would require time-consuming and expensive exercises to produce estimates for relatively small amounts and flows of carbon (e.g. compared to carbon stocks, sinks and sources associated with the LULUCF.and energy sectors).

Model-based methodologies

Model-based methodologies are by far the most common approaches to estimating quantities and flows of carbon associated with harvested wood. The general technique involves:

- Defining different categories of HWP.

- Allocating wood-based carbon as it is harvested over time to the HWP categories.
- Modelling the retention (and, by the same token, loss) of carbon in each HWP category.

The categories of HWP are defined primarily in terms of a mixture of their end uses and, most importantly service lives in primary/secondary use. For example, Thompson and Matthews (1989) defined the following categories of HWP:

- Waste, bark and fuel
- Pulpwood
- Particleboard
- Medium density fibreboard
- Pallet and packaging
- Fencing
- Construction and engineering
- Mining
- Other.

Allocation coefficients (such as shown in Figure 2) are then used to determine the quantities of harvested wood (mainly stemwood but sometimes branchwood and possibly roots) to the different product categories. The ‘residency’ of the carbon in each of the product categories is then modelled using time dependent functions to describe the gradual (or rapid) loss of carbon as products decay or are destroyed. A central assumption made in any such model-based approach is that carbon stocks and stock changes in harvested wood products depend on the relative magnitudes of two properties:

- The amounts of carbon transferred by harvesting from forests to wood product pools.
- The service lives of any harvested wood products.

Models have been developed by a number of research groups in different countries to investigate the interactions between forest and HWP carbon dynamics. The modelling approaches adopted by different research groups (Table 15-2) are very similar and can be summarised in a diagram such as Figure 15-2. Flows of wood or carbon to the HWP pool are usually derived directly from yield tables and appropriate produce conversion tables, or (of most relevance to this discussion) from timber consumption statistics. Transfers of carbon from wood products to secondary use, recycling, landfill and eventual oxidation to the atmosphere are estimated by applying time-dependent exponential decay or hazard functions to the stocks of products.

Table 15-2. Overview of carbon accounting models representing harvested wood products. (Other carbon pools covered by models are also listed)

Country of origin	**Model Name**	**Forest types represented**			**Model compartments included**					**References**
		Even-aged production	**Multi-aged production**	**Semi-natural old growth**	**Forest**	**Litter**	**Soil**	**Wood products**	**Fossil energy displacement**	
Australia	FULLCAM	✓			✓	✓	✓			NCAS (2001)
Canada	CBM-CFS CBM-CFS2 CBM-CFS3	✓	✓	½	✓	✓	✓	✓		Apps and Kurz (1993), Kurz *et al.* (1993). Kurz *et al*. (2009)
Netherlands/ Finland	CO$_2$fix	✓	✓	½	✓	✓	✓	✓	½	Nabuurs and Mohren (1993, 1995), Nabuurs (1996)
Switzerland	-	✓	✓		✓	✓	✓	✓	✓	Fischlin and Bugmann (1994)
USA	FORCARB	✓	✓	½	✓	✓	✓	✓		Heath and Birdsey (1993), Plantinga and Birdsey (1993)
USA	HARVCARB							✓		Row and Phelps (1996)
USA	WOODCARB							✓		Skog and Nicholson (1998)
USA	-	✓	✓	½	✓	✓	✓	✓		Harmon *et al.* (1990)
USA/Austria	GORCAM	✓			✓	✓	✓	✓	✓	Marland and Marland (1992), Marland and Schlamadinger (1995), Schlamadinger and Marland (1998)
USA	-							✓		Marland and Marland (2003)
United Kingdom	C-FLOW	✓	½		✓	✓	✓	✓		Dewar (1990, 1991), Dewar and Cannell (1992)
United Kingdom	CARBINE	✓	½	½	✓	✓	✓	✓	✓	Thompson and Matthews (1989)

Note: References given here represent original or early descriptions of models or predictions made using them. For many models more recent references exist and for some there is now a substantial body of literature which cannot be repeated here.

The structure of models of the wood products pool varies in the level of detail represented. In some models this might consist of a single, hypothetical and generic wood product with dynamics assumed to follow a simple first-order batch process. In other models allocation of carbon and retention in wood products is well detailed, with the complete range of wood products represented (Figure 15-2), however in many respects this apparent thoroughness is not underpinned by hard data. For example, Thompson and Matthews (1989) presented graphs showing the time-dependent loss of carbon for each of the different wood product categories, but data to support these assumptions were very limited. Representation of carbon stocks in wood products is often limited to primary use, and in particular dynamics of carbon in landfilled wood products may be ignored in some models.

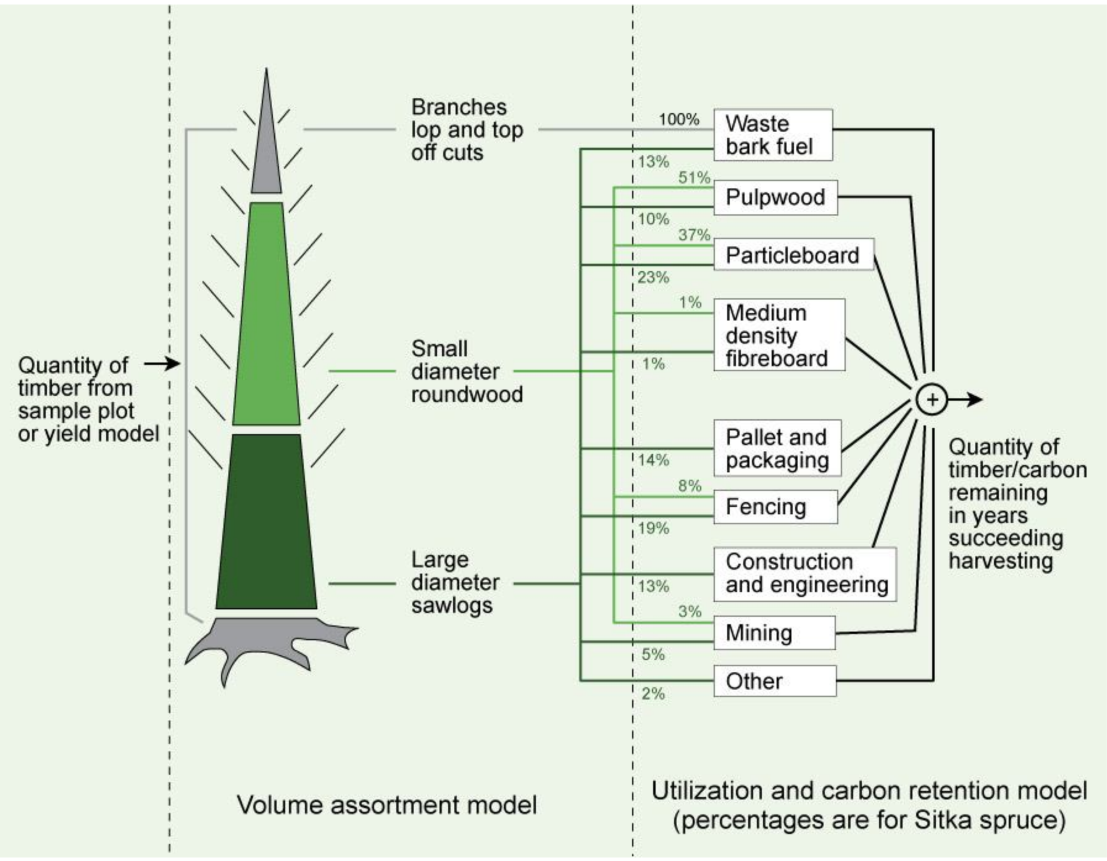

Figure 15-2. Schematic diagram of structure of HWP carbon model (based on the CARBINE model of Thompson and Matthews, 1989).

Model-based methodologies are evidently in common use in many countries and, in some cases, these models are well developed with a sophisticated representation of the follows of harvested carbon through the forest industry sector, primary use, secondary use and disposal. In principle, the approach could be adapted readily for the estimation and monitoring of carbon stocks, sinks and sources at national scale; indeed some exploratory work has already been carried out (Thomson and Milne, 2005). However, an better ‘evidence base’ would be required for many of the parameters used in the model-based approach, notably for HWP allocation factors and residence times/dynamics of different HWP categories. Despite this, the approach remains a relatively low-cost and efficient solution to the problem of monitoring HWP carbon.

15.4 Accounting methods for HWP carbon

Methods for monitoring HWP carbon need to work in explicit conjunction with any reporting framework adopted by countries. At present, the reporting approach adopted as the default within IPCC guidelines is to assume that all carbon in harvested wood is oxidised to the atmosphere instantaneously (and by implication carbon stocks in HWP are zero for all time). This accounting method, generally known as the 'IPCC default' at least has the advantage that it is easy to implement – i.e. no HWP carbon monitoring system is required! However, he proposal for keeping inventories of carbon retained in wood products has resulted in discussions about how the reporting and accounting should be done. When a forest is harvested and wood products are produced which party will report the carbon stocks or flows related to wood products? If the carbon in wood products increases, will some party report the increase as part of a greenhouse gas emissions account? Will the party that grew and harvested the trees show that some of the carbon was not discharged as CO_2 when the trees were harvested, or will the party that accumulated wood products show an increase in carbon? A 1998 meeting in Senegal (see Brown et al., 1998 and Lim et al., 1999) outlined 4 possibilities for carbon reporting methods beyond the simple 'IPCC default' approach, known as:

- The atmospheric flow approach
- The stock change approach
- The production approach.

More recently a fourth option, known as the 'simple decay approach' has been proposed by Ford-Robertson (2003).

15.5 Atmospheric flow approach

Figure 15-3 illustrates how HWP carbon would be reported by different countries under the atmospheric flow approach. Emissions of carbon arising from the decay or destruction of HWP are reported by the Annex 1 countries; however, the 'sinks' of carbon into HWP due to transfers of carbon from the forest are ignored. While the sink due to harvested wood production is not included, sinks and sources in forests, including sources due to reductions of carbon stocks arising from harvesting, are fully reported in the LULUCF sector. For example, the UK would report the emissions due to decay and destruction of both home-produced and imported HWP, but would not report any 'sinks' due to home-grown production or importation. Any reductions in UK forest carbon stocks due to harvesting would still need to be accounted for.

15.6 Stock change approach

Figure 15-4 illustrates how HWP carbon would be reported by different countries under the stock change approach. The 'sinks' of carbon into HWP within a country due to transfers of carbon from forests are reported by the Annex 1 countries. For example, the UK would report the 'sink' due to consumption of home-produced wood as well as wood from imported from the Annex 1 and the non-Annex 1 country. Emissions of carbon arising from the decay or destruction of HWP are also reported by the Annex 1 countries. Sinks and sources in forests, including sources due to reductions of carbon stocks arising from harvesting, are fully reported in the LULUCF sector. Implicitly, the stock change approach would report changes to actual stocks of carbon as wood is harvested, traded, utilized, and disposed of. For example, the UK would report the sinks due to the consumption/utilisaton of all HWP in the UK, both home-produced and imported as well as emissions due to decay and destruction of HWP in the UK, both home-produced and imported.

Some parties have expressed concern that including carbon sinks due to imported HWP produced from forests in non-Annex 1 countries could provide unintended incentives for unsustainable harvesting in those countries. This has led to a proposed modification to the stock change approach which would involve limiting reporting of HWP transactions to Annex 1 countries, as illustrated in Figure 15-5. For example, the UK would report the sinks due to the consumption/utilisaton of all HWP in the UK, both home-produced and imported as well as emissions due to decay and destruction of HWP in the UK, both home-produced and imported. However, only imports from Annex 1 countries would be considered. This would mean that any carbon sink in the UK due to importation of HWP from non-Annex 1 countries could not be reported; by the same token, any emissions due to the decay or destruction of HWP from non-Annex 1 countries would also not be declared.

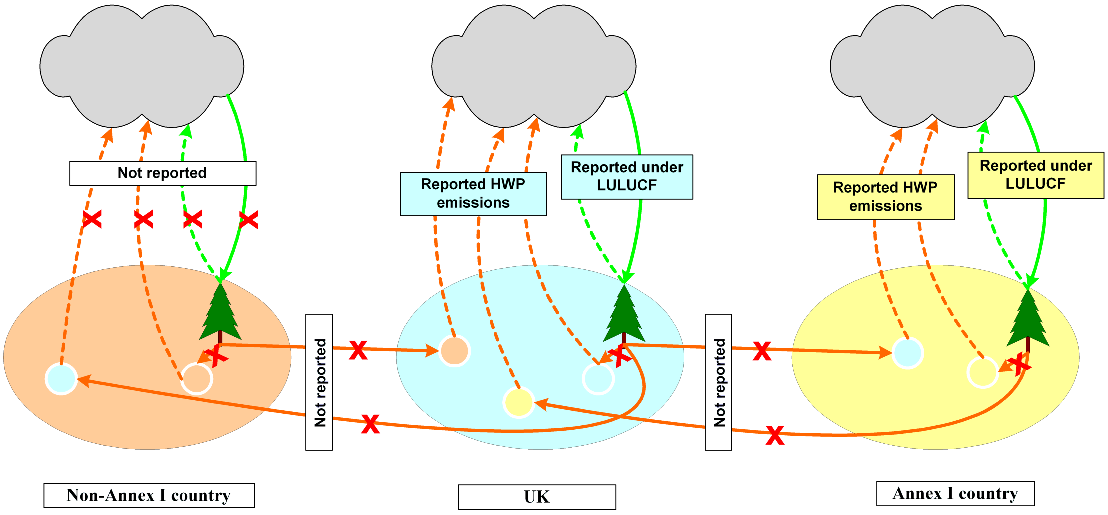

Figure 15-3. Reporting of HWP carbon under the atmospheric flow approach using the example of transactions between 3 countries – the UK, another Annex 1 country and a non-Annex 1 country. Solid/broken green lines show removals/emissions of carbon due to forest dynamics, reported in the LULUCF sector. Solid orange lines show transfers of carbon from forests to HWP and between the three countries arising from trade. Coloured circles indicate the country origins of pools of HWP carbon in each country. Broken orange lines show emissions of carbon due to decay and destruction of HWP. Coloured labels indicate the sinks and sources of carbon actually reported by the three countries.

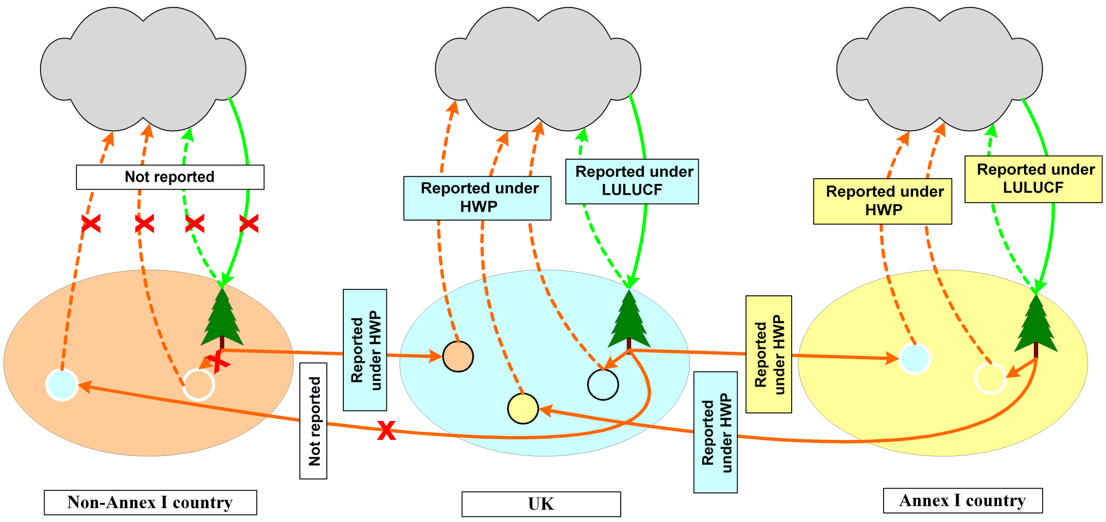

Figure 15-4. Reporting of HWP carbon under the stock change approach using the example of transactions between 3 countries – the UK, another Annex 1 country and a non-Annex 1 country. See Figure 2 for details of figure colour and labelling conventions. In addition, black outlines to coloured circles indicate carbon reservoirs in HWP included in the UK account.

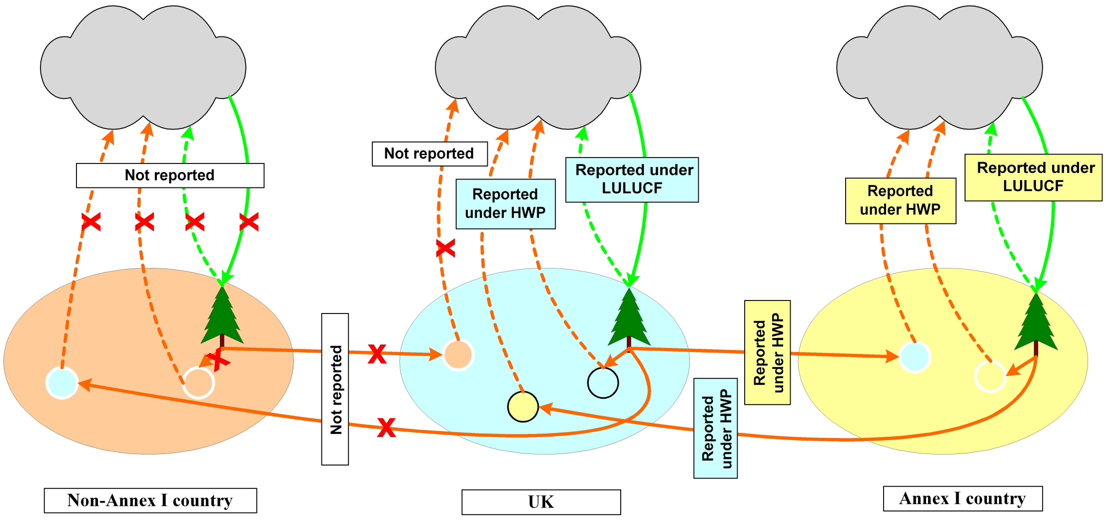

Figure 15-5. Reporting of HWP carbon under the 'restricted' stock change approach using the example of transactions between 3 countries – the UK, another Annex 1 country and a non-Annex 1 country. See Figure 2 for details of figure colour and labelling conventions. In addition, black outlines to coloured circles indicate carbon reservoirs in HWP included in the UK account.

15.7 Production approach

Figure 15-6 illustrates how HWP carbon would be reported by different countries under the production approach. The 'sinks' of carbon into HWP from forests due to production in each country are reported by the Annex 1 countries. For example, the UK would report the 'sink' due to consumption of home-produced wood, both consumed in the UK and in other countries (due to exports). Emissions of carbon arising from the decay or destruction of home-produced HWP, regardless of where they end up, are also reported by the Annex 1 countries. Sinks and sources in forests, including sources due to reductions of carbon stocks arising from harvesting, are fully reported in the LULUCF sector. For example, the UK would report the sinks due to home-produced HWP, regardless of whether they were consumed in the UK or abroad. Emissions due to decay and destruction of home-produced HWP would be reported in a similar manner.

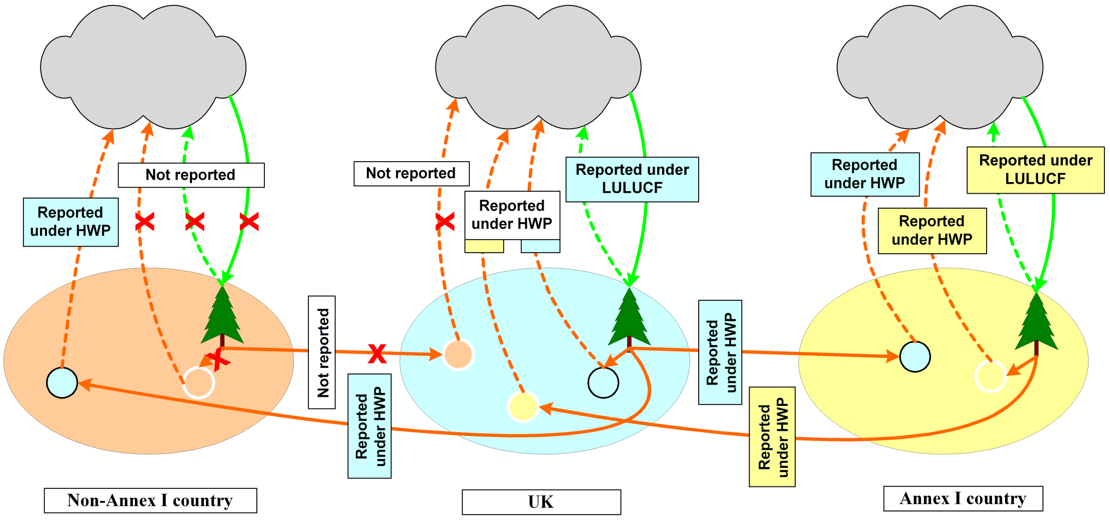

Figure 15-6. Reporting of HWP carbon under the production approach using the example of transactions between 3 countries – the UK, another Annex 1 country and a non-Annex 1 country. In addition, black outlines to coloured circles indicate carbon reservoirs in HWP included in the UK account.

15.8 Simple decay approach

Figure 15-7 illustrates how HWP carbon would be reported by different countries under the simple decay approach. On the surface, the conventions seem very similar to the production approach. However, in practice, the simple decay approach is far more pragmatic. As indicated in the figure, there no attempt to represent transactions of timber between producers and consumers, instead, harvested carbon remains attributed to the forest and, while still 'resident', is reported as part of the LULUCF account rather than as a distinct category. Similarly, the 'residence' of HWP carbon is estimated using a very simplistic model-based method.

15.9 Matching monitoring and reporting methods

The preceding discussion has highlighted the essential features of inventory-based and model-based monitoring methodologies. Table 15-3 considers how these methodologies might be applied to the monitoring of HWP carbon under the different reporting approached also described above.

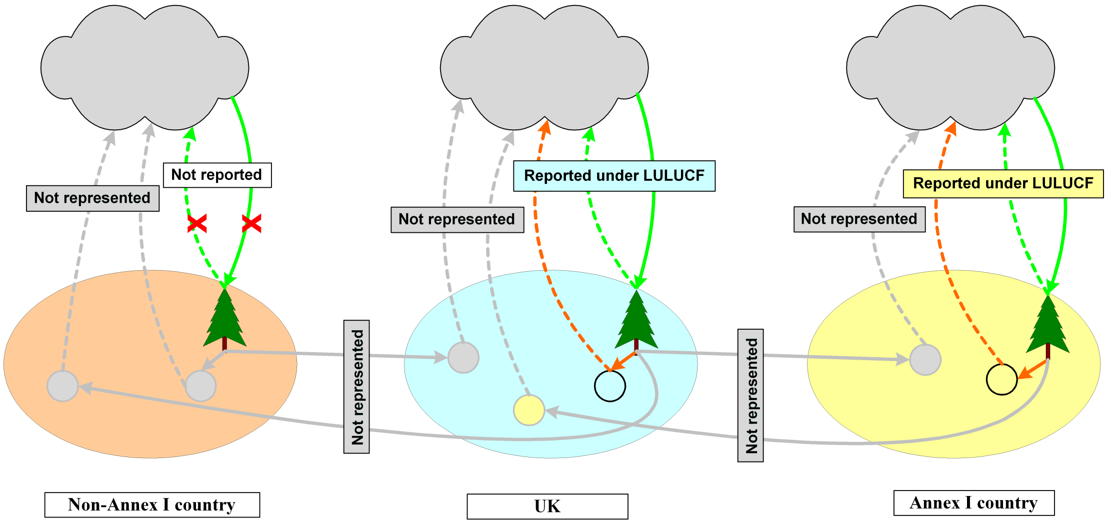

Figure 15-7. Reporting of HWP carbon under the simple decay approach using the example of transactions between 3 countries – the UK, another Annex 1 country and a non-Annex 1 country. Solid/broken green lines show removals/emissions of carbon due to forest dynamics, reported in the LULUCF sector. The report for the LULUCF sector includes an allowance for carbon retained in HWP produced from forests in each country (solid/broken orange lines), which is estimated using a very simplistic model-based method. Transfers of HWP carbon between countries and due to trade and related country emissions (grey lines) are not considered.

As a general point, the review of methodologies has already revealed that a fully inventory-based methodology would not be practical for any of the reporting approaches due to the technical difficulties associated with direct assessment of stocks in many HWP categories – most obviously landfill. It follows that any methodology adopted by the UK or other countries might involve elements of direct inventory for key product categories, with the remainder covered by model-based methods. More probably, an entirely model-based methodology may be adopted as a cost-effective solution to HWP carbon monitoring and reporting. Model-based approaches are particularly well suited to tracking HWP carbon arising from different origins or going to different destinations, as would be required under the 'restricted' stock change, production and simple decay approaches.

15.10 Conclusions

Methods and approaches for reporting sinks and sources of carbon due to harvesting and utilization of wood products are well advanced. In principle, any of the main reporting approaches can be implemented using a mix of inventory-based and model-based methodologies. The role of inventory-based methodologies is likely to be limited because of their cost and complexity and in particular difficulties in establishing a clear chain of custody for all HWP. In contrast, model-based approaches are relatively low-cost and efficient and can produce reasonably accurate estimates of HWP carbon stocks, sinks and sources, provided that a database of underpinning statistics and parameters is developed and maintained. At first inspection, the UK seems well-placed to implement the main options for HWP carbon accounting in terms of existing statistics reported on transactions of HWP, however, this requires closer investigation and some elaboration of current reporting details may be needed. The research and development needed to provide defendable parameters for a model-based estimation and reporting methodology (e.g. HWP allocation coefficients and residence times) still needs to be specified; a decision is needed about the specific approach to be adopted for HWP reporting before a definitive position can be reached.

Table 15-3. Implications of different HWP reporting approaches for monitoring of UK stocks, sinks and sources

Accounting method	**Implications for monitoring**
Atmospheric flow	• A direct inventory approach is not well suited to assessment of emissions of HWP carbon, as stock changes derived from periodic inventories give net sink/source, not the gross source required for this reporting approach. • It might be possible to infer estimate the emissions of HWP carbon from periodic stock inventories in conjunction with HWP consumption data and some modelling of results. However, if modelling is needed, might as well use model-based approach fully. • Periodic UK timber production forecasts and statistics on imported HWP could be used as inputs to a model-based monitoring system. • Some key parameters (e.g. product allocation coefficients and lifespans) used by model-based methods would require validation through supporting research.
Stock change	• Direct inventories of wood products in UK possible for some key HWP categories but not all, notably landfill. • Direct inventory should be able to explicitly represent stocks, sinks and sources due to HWP in England, Wales, Scotland and Northern Ireland. • Tracking of ‘provenance’ of HWP stocks assessed in a direct inventory would be very difficult, probably impossible – this causes problems for ‘restricted’ stock change approach. • Periodic UK timber production forecasts and statistics on imported HWP could be used as inputs to a model-based monitoring system. • It is possible that sufficient information is available to permit distinction of HWP imported from Annex I and non-Annex I countries within a model-based monitoring framework, but this requires further investigation; it is possible that supplementary data may be required. • Some key parameters (e.g. product allocation coefficients and lifespans) used by model-based methods would require validation through supporting research.
Production	• Direct inventories of wood products in UK possible for some key HWP categories but not all, notably landfill. • Direct inventories of wood products in countries other than UK unfeasible. • Periodic UK timber production forecasts and statistics on exported HWP could be used as inputs to a model-based monitoring system. • Some key parameters (e.g. product allocation coefficients and lifespans) used by model-based methods would require validation through supporting research. This may need to be quite complex because of the possible requirement to represent utilization patterns for HWP exported to different countries.
Simple decay	• Direct inventory not relevant to this approach. • Periodic UK timber production forecasts and statistics on exported HWP could be used as inputs to a model-based monitoring system. • Some key parameters (e.g. product allocation coefficients and lifespans) used by model-based methods would require validation through supporting research. However, by definition under this reporting approach, simplistic and generalised assumptions would be taken.

15.11 Acknowledgements

The author wishes to acknowledge the contributions of their colleagues in Forest Research and the Forestry Commission to the development of the ideas and content of this report. In particular the statistical advice of Simon Gillam (Forestry Commission) and his statistics group is gratefully acknowledged.

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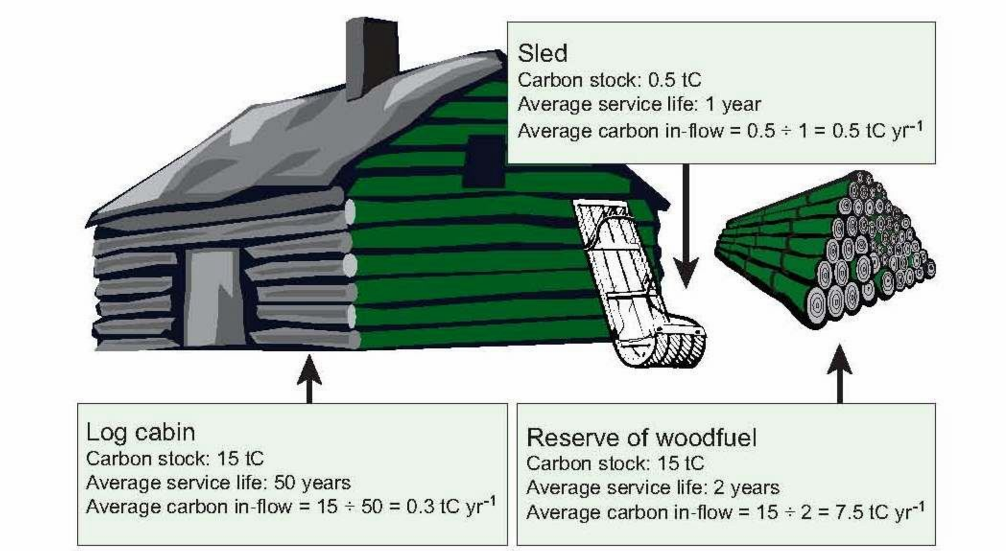
15.13 *Appendix 1. The key drivers of carbon dynamics in primary wood products*

Suppose that a family moves to a previously uninhabited area of forest. As an integral part of their daily lives, the family harvests some of the trees in the forest to make essential items from wood, as illustrated in Figure A1.1 (after Matthews et al., 2007).



Sled
Carbon stock: 0.5 tC
Average service life: 1 year
Average carbon in-flow = 0.5 ÷ 1 = 0.5 tC yr^{-1}

Log cabin
Carbon stock: 15 tC
Average service life: 50 years
Average carbon in-flow = 15 ÷ 50 = 0.3 tC yr^{-1}

Reserve of woodfuel
Carbon stock: 15 tC
Average service life: 2 years
Average carbon in-flow = 15 ÷ 2 = 7.5 tC yr^{-1}

Figure A1-15-1. A log cabin, a sled and a stock of woodfuel.

A log cabin, a sled and a stock of woodfuel illustrate the relationships among carbon stocks, flows and the service lives of wood products:

- Log cabin (long-lived, contains a relatively large amount of carbon). Upon arrival, the family first builds a log cabin. They build this from wood harvested from trees in the forest, and the wood in the cabin contains a stock of 15 tonnes of carbon. Every 50 years, the log cabin needs replacing, so every 50 years the family needs to harvest another 15 tC of wood, giving an average annual in-flow of carbon to the log cabin of 0.3 tC y^{-1}.
- Sled (short-lived, contains a relatively small amount of carbon). The family then builds a sled and more wood is harvested for this purpose. Compared to the house, the sled is quite small and contains only 0.5 tonnes of carbon. Also, the sled is not very durable, and needs to be replaced every year so the family needs to maintain a sustained in-flow of 0.5 tC y^{-1} of wood to make replacement sleds and maintain the carbon stock.
- Stockpile of fuel logs (very short-lived, contains a relatively large amount of carbon). The family needs a stockpile of fuel logs for cooking and for heat in the winter. The climate is cold, so the stockpile quite large, with the carbon stock as big as observed for the log cabin (15 tC of wood). This is despite the product being very short-lived – wood is harvested in one year and seasoned, then burned the following year. Logs therefore last for 2 years and the family needs to maintain a sustained in-flow of 7.5 tC y^{-1} to maintain the stockpile of wood.

One of their first acts is to build a place to live mainly out of wood. The family also requires fuel for cooking and for heating, so they maintain stockpile of firewood. As a third example, they require a sled for transport, which they also make from wood.

These three examples of harvested wood products the house, firewood and sled require different amounts of wood to make, and they last for different lifespans. Often, scientists and researchers use these properties to estimate the size of carbon stocks in harvested wood products (and of any associated carbon sink and source). For example, a researcher might find from timber trade statistics that the annual amount of carbon consumed to make homes in this region of the world is 0.3 tC y^{-1} (tonnes carbon per year). They may also know that, on average, the wood in a house in this region lasts for 50 years. They might use these numbers to estimate the carbon stock in harvested wood contained in houses in the region as:

Carbon stock in houses = 0.3 x 50 = 15 tC.

Calculations such as this can be a valid way of obtaining indicative estimates of quantities of carbon in particular types of wood products, although there can be complications, as discussed later. It is most important to realise that these calculations do not represent a reliable description of the processes that cause carbon stocks in wood products to increase or decrease. For example, these sorts of analyses have led some commentators to suggest that, if the lifespans of wood products can be extended, then the quantity carbon in wood products should increase. To illustrate, it might be suggested that if the lifespans of timber used to build the house in Figure 1 can be extended from 50 years to 100 years, then the carbon stock in houses should double. However, there is a simpler and more obvious approach to estimating the size of wood product carbon stocks, which is also a more realistic representation of the processes determining the carbon dynamics. This approach recognises that the main factor driving the creation of a particular type of wood product is the requirement that product. For example, the family living in the region of the world illustrated in Figure A1.1 use just one house. Hence the carbon stock in harvested wood in houses in the region can be calculated as:

Carbon stock in houses = number of houses in service x average quantity of carbon in wood per house = 1 x 0.3 = 0.3 tC.

Because timber in a house in this region has a lifespan of about 50 years, the family replaces the timber in the house roughly every 50 years. If the lifespan of the houses is doubled somehow to 100 years, it is unlikely that the family would build and maintain two houses instead of one. It is more likely that the family would replace their single house every 100 years instead of every 50 years. As a consequence, the number of houses stays the same, even though the lifespan has been doubled. (One other consequence of this would be that the flow of carbon into the wood products pool in houses would decrease, because less wood needs to be harvested to maintain the same number of houses over time.)

16. Development of Bayesian models of future land use change (WP 2.13)

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16.1 Introduction

The guidance (IPCC 2003) for countries required to submit annual estimates of emissions and removals of carbon dioxide to/from the atmosphere under the UNFCCC recommends that land use change should be considered using a matrix of changes of area. A matrix contains data of not only changes in the area in any land category between years but information on the areas moving between each of the different pairs of categories. This detail is required because the rates of emission or removal vary between the different transitions, e.g. carbon is normally lost (as CO_2) more quickly when land is disturbed than is taken up in the reverse process. In most countries annual estimates of land in different categories is usually available but the different transitions for a matrix are seldom produced annually, if at all.

In the UK, the Forestry Commission, Defra and other bodies produce official land use data annually. The detail is best in England but generally the areas in forestry, agriculture and other land types are published. However land use change (LUC) matrices are only produced intermittently by CEH for Defra from the results of the Countryside Survey. These have been carried out in 1984, 1990, 1998 and another in 2007, which is yet to be fully reported. They allow the land category transition data to be constructed by revisiting the same locations at each survey date and recording the change in land use on a field by field basis.

The land categories used for the UK GHG Inventory are Forest Land, Grassland, Cropland, Settlements and Other Land. Grassland is for some estimation purposes split between managed and unmanaged grassland. These types are labelled differently here (see caption Equation 16-1) but are directly equivalent.

The question to be addressed in this section of the Land Use Change GHG Inventory contract is whether it is possible to infer annual adjustments to the land use change matrices produced from the intermittent surveys by using the annually published land areas.

The primary difficulty in answering this is that if there are *n* land categories then the complete the matrix information on *n (n-1)* transitions is required to describe the changes over a single year. However the differences in the annual data between two years only provide *n* values. Over longer periods additional data are available from the series of annual data but these cannot be used directly to assess annual changes to the LUC matrix. The final aim of the work is to produce a LUC matrix for which simple time series models describe the variations in the matrix elements and the parameters of that model are calibrated against the annual land area data using Bayesian statistical methods. The time series model could be either a stochastic description of the variation or a deterministic relationship to economic or policy drivers. However as there is no prior information on how the probability of annual transitions between land categories are related by such models a simpler approach as been adopted so far. This assumes that annual land use transition probabilities are independent of each other, do not depend on earlier values and are not related to other drivers. A Bayesian approach has then been used to “estimate” time series of changes in the probabilities as described below.

16.2 Model structure

The basic approach to the model of using land use change matrices to track changes in stocks of carbon is shown by Equation 16-1.

$$\begin{bmatrix} {}_{A}A_{t} \\ {}_{G}A_{t} \\ {}_{W}A_{t} \\ {}_{D}A_{t} \\ {}_{O}A_{t} \end{bmatrix} = \begin{bmatrix} {}_{AA}p & {}_{GA}p & {}_{WA}p & {}_{DA}p & {}_{OA}p \\ {}_{AG}p & {}_{GG}p & {}_{WG}p & {}_{DG}p & {}_{OG}p \\ {}_{AW}p & {}_{GW}p & {}_{WW}p & {}_{DW}p & {}_{OW}p \\ {}_{AD}p & {}_{GD}p & {}_{WD}p & {}_{DD}p & {}_{OD}p \\ {}_{AO}p & {}_{GO}p & {}_{WO}p & {}_{DO}p & {}_{OO}p \end{bmatrix} \begin{bmatrix} {}_{A}A_{t-1} \\ {}_{G}A_{t-1} \\ {}_{W}A_{t-1} \\ {}_{D}A_{t-1} \\ {}_{O}A_{t-1} \end{bmatrix}$$

Equation 16-1: Land use change transition or probability matrix. p is probability of transition = fraction of land changing. Each column gives the probability of an area of land e.g. Arable in column 1, changing to a different use. Row 1 gives the probability of land remaining in Arable and each other row gives the probability for the transition to a different use e.g. Arable to Grassland. The sum of the probabilities in each column is 1 because all land remains in existence. ${}_{X}A_{t}$ and ${}_{X}A_{t-1}$ area areas of land of type "X" in years t and $t-1$. Subscripts: A – Arable land (IPCC Cropland), G – Grassland (IPCC Grassland), W – Woodland (IPCC Forest Land), D – Developed land (IPCC Settlements), O – Other land (IPCC Other Land

The values for each column give the probabilities that unit area of an initial specific land use (or the fraction of the initial land use) will change to any other, e.g. column 1 in Equation 16-1 gives the values for changes from Arable land to other uses. The values of the diagonal of the matrix are the probability (or fraction) that no change will take place. The diagonal values are therefore not independent but for each column (land use) can be calculated as the difference between unity and the sum of the "non-diagonal" values in that column.

Land use change data is not normally available as the probability or fraction of change for each land use transition between reference dates but as the area of change (or no change) between these dates. The probabilities of change are estimated by dividing each entry in a matrix column by the sum of the column. Although it is natural to think of the total area in a country that will change from one use to another over a specific period this form of data cannot be readily used by a mathematical model. It is also the case that the total change for the country is made up of decisions by many individual land owners and will involve statistical variability hence an overall probability of change is the most appropriate basis for modelling. If the area change data has been obtained between two dates more than a year apart then the annual probability of change can be estimated by matrix algebra. This requires calculation of the *n*th root of the measured area matrix but this is easy using a software package that includes matrix algebra.

Equation 16-1 describes a LUC matrix that is constant in time, which is the intrinsic assumption from resampling surveys over a specific period. The matrix provides the cumulative change over the period and hence the annual probability matrix is an average for the period. Our purpose however is to construct a matrix whose elements change with time. To simplify each matrix element in such a model might have an initial value that might then change with time but retain some memory of previous values or be related to economic variables. Only LUC transitions that were believed to change significantly with time would require this structure and the probabilities of land not changing can be calculated from the knowledge that the column sum must equal unity. However this approach is not followed here as the LUC matrix will be allowed to vary anuually.

16.3 Area data

In order to assess the usefulness of the model outlined above and to explore calibration methods recent data for land use and change have been chosen. The Forestry Commission reports annually the area of forest land in each of England, Scotland, Wales and Northern Ireland (FC 2006). The June Agricultural Census is conducted in each of the four UK countries by the appropriate agriculture departments. However comprehensive data on developed areas is only readily available for England. The Ordnance Survey prepares this data on changes in urban land use in England for The Department of Communities and Local Government (DCLG 2006).

The annual data from 1990 to 2005 for the area of Arable Land, Grassland, Woodland, Developed Land and Other Land in England was initially chosen as a test series for the calibration of the parameters of an annual LUC transition probability matrix model. The time series are shown in Figure 16-1. Longer-term annual data from 1950 onwards is available for woodland and agriculture in Great Britain but other land uses and the situation in Northern Ireland are less well documented. Some information is available from the Monitoring Landscape Change reports (MLC 1986) and from surveys in Northern Ireland and this has been used in the GHG Inventory. Further work will be required to construct annual data for each country for each land type but this has been postponed until after initial testing and calibration of the matrix model using the 1990 to 2005 English data.

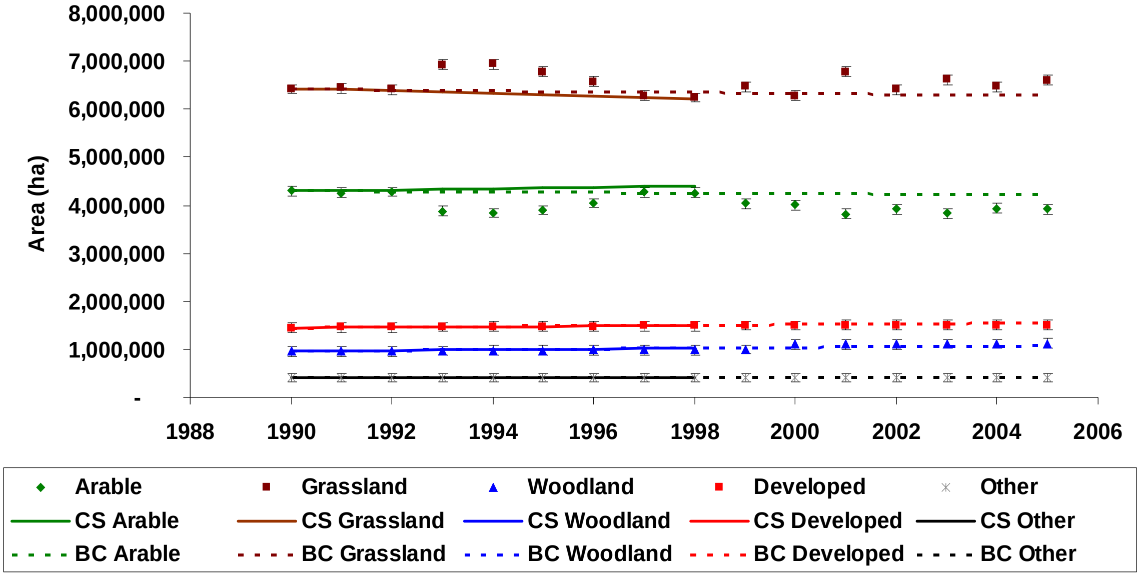

Figure 16-1. Published areas of land use in England. Area of Other land estimated by difference of sum of Arable, Grassland, Woodland and Developed from total area of England. Also Bayesian calibration of constant land use transition matrix model for England. Graph shows trend in annual areas of land use estimated from probability matrix with values from Countryside Survey (CS) before (solid lines) and after Bayesian calibration (BC) (dash lines) compared to published annual data (points).

The data from the Countryside Surveys of 1990 and 1998 (known as Countryside Survey 2000) have been used extensively for UK LUC GHG purposes and the LUC matrix over this period has been selected here to provide preliminary parameter values for the LUC probability matrix. (See Table 16-1)

Table 16-1A. Land use change matrix for land in England for period 1990 to 1998. Units are hectare. Land in the Other category (e.g. rock, water etc) is assumed to remain unchanged

From **To**	**Arable**	**Grassland**	**Woodland**	**Developed**	**Other**	**Total 98**
Arable	4,053,000	503,030	4,362	5,007	-	4,565,399
Grassland	442,010	5,046,800	69,450	27,180	-	5,585,440
Woodland	27,150	71,350	1,298,000	16,680	-	1,413,180
Developed	17,030	67,690	9,938	1,396,000	-	1,490,658
Other	-	-	-	-	394,700	394,700
Total 90	4,539,190	5,688,870	1,381,750	1,444,867	394,700	13,449,377

Table 16-1B Annual probability of land use change in England on average over period 1990 to 1998. Annual changes are assumed to be constant.

From **To**	**Arable**	**Grassland**	**Woodland**	**Developed**	**Other**
Arable	0.9854	0.0123	0.0001	0.0004	0.0000
Grassland	0.0135	0.9845	0.0068	0.0025	0.0000
Woodland	0.0007	0.0017	0.9922	0.0015	0.0000
Developed	0.0004	0.0016	0.0009	0.9957	0.0000
Other	0.0000	0.0000	0.0000	0.0000	1.0000

16.4 Bayesian calibration and initial testing

The model proposed for assessing annual land use change matrices has many parameters relative to the available data (i.e. published annual area of land use). It is therefore unlikely that the model could be fitted using normal statistical techniques. The annual area data is however also subject to uncertainty and from the Countryside Survey data for land use change there is some information on the uncertainty of the matrix elements. Bayesian methods were therefore used to calibrate the matrix elements to maximise the likelihood of element, i.e. probability of change, values given the uncertainty of the annual area data. Van Oijen et al (2005) have described a numerical method of varying the parameters of a model using a Monte Carlo Markov Chain simulation and tracking the likelihood of the output values (in this case annual area of land uses) from the model compared to the measured (in this case published) values until convergence is achieved.

To explore these methods a LUC matrix model, with constant transition probabilities, was implemented within an Excel spreadsheet. Uncertainty ranges for the probability elements of the matrix were set from the Countryside Survey matrix and knowledge of the uncertainty due to the sampled nature of the survey. It was assumed for initial testing that the matrix was constant over the period 1990 to 2005 and that the annual area data have an uncertainty of +/- 100,000 ha. A MCMC run for 50,000 different sets of probability elements starting with those from Table 16-1B is illustrated in Figure 16-2. The uncertainty in the transition probabilities prior to Bayesian calibration was assumed to be +/-30% of the value in the CS derived matrix. The LUC transition matrix after Bayesian calibration is shown in Table 16-2. The resulting annual area data, starting from the published 1990 values, is also shown in Figure 16-1.

Table 16-2 Constant annual probability of land use change in England over period 1990 to 2005 using Bayesian calibration from original CS matrix of Table 1B.

From To	Arable	Grassland	Woodland	Developed	Other
Arable	0.9813	0.0115	0.0001	0.0004	0.0000
Grassland	0.0173	0.9855	0.0061	0.0022	0.0000
Woodland	0.0009	0.0015	0.9929	0.0012	0.0000
Developed	0.0004	0.0015	0.0010	0.9963	0.0000
Other	0.0000	0.0000	0.0000	0.0000	1.0000

16.5 LUC matrix with variable transition probabilities

The area time series generated by the constant transition probabilities of the LUC matrix of Table 16-3 can be seem from Figure 16-1 to pass along central trends compared to the published data and do not follow the variations in individual recorded areas. The likelihood is that the transition probabilities change year to year, i.e. each is a function of time. In order to generate these time series for further investigation the following procedure was adopted: i. Start with land areas for 1990 and prior probability range of transition values from the constant matrix, ii. Calibrate transitions to land use data for 1991 via Bayesian method, iii. Repeat for 1991 ->1992, 1992 ->1993 etc. etc. Due to the higher computing demands this approach was implemented with MCMC runs of 20,000 iterations and to allow the transition values to vary the prior probability ranges were extended considerably. The time series of areas produced from the set of matrices thus obtained in shown in Figure 16-2.

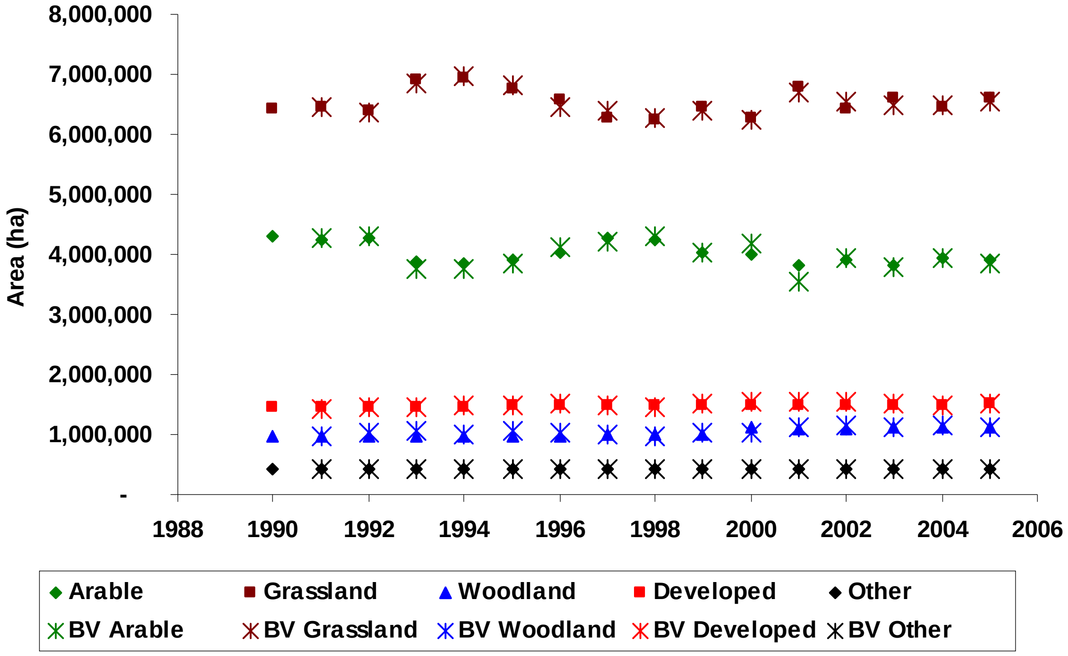

Figure 16-2. Time series of land use in England. Areas derived from starting values of 1990 using set of LUC matrices with time varying transition probabilities determined by Bayesian calibration (* BV) compared to published (points) area data.

16.6 Variation in LUC transition probabilities

The variation in each transition probability was investigated by plotting the values from other uses to Grassland, to Arable, to Woodland and to Developed. Most of the transitions actually showed little variation but those between Arable and Grassland showed interesting variation with time, which might indicate farmers reducing crops areas. Figure 16-4 shows the relationship between a scaled version of the transition probabilities from Arable to Grassland and an index of farming profits based on published (Defra 2007) UK data. It can be seen that the low value for transitions out of Arable is 3 years later (1998) than the peak of profits (1995). In other words there is a lagged negative correlation between shifts out of crops and farm profits. Maybe the farmer keeps more area in crops when these have recently been profitable. Obviously more work needs to be done on the relationship between land use transitions and economics but it would appear that changes between arable land and other uses are those that vary most.

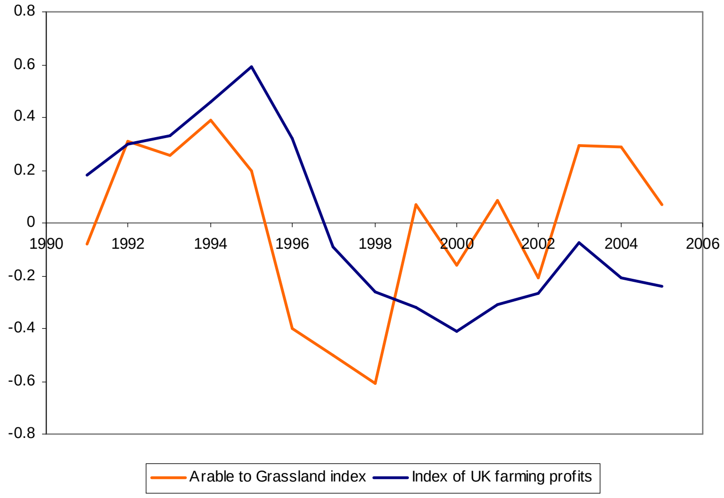

Figure 16-4. Relationship between an index of UK farm profits and transitions of land from Arable to Grassland in England.

It would however be preferable to have annual area data for managed and unmanaged grassland separated because farm management decisions are more likely to involve other grassland areas on-farm rather than land off-farm. This requires a larger LUC matrix and therefore to improve computational speed a Fortran programme was written to carry out the Bayesian calibration. This programme, as well as the most likely values, calculated the mean and standard deviation of the sample parameter and resulting land areas from the values selected by the MCMC process.

16.7 Artificial data

An enhanced approach with six land use categories and starting matrix data was therefore considered to be important for understanding the drivers for land use change. The six categories of land for the enhanced analysis are: Arable, Managed Grass, Unmanaged Grass, Woodlands, Developed and Other. In addition, although the preliminary calculations described above strongly suggested that the Bayesian approach to estimating LUC matrices was viable, it was decided to make artificial land use area time series and matrices of change to test the approach before proceeding to using real six category land data. The structure of the six category land use change model is shown in Equation 16-2.

The artificial data was based on the real English data but with some simplification. A LUC transition matrix was chosen initially (Table 16-3) and used for the period 1990 to 1991. A set of 14 LUC matrices (for 1991-1992, 1992-1993, 2004-2005) was then generated by randomly varying the values of the matrix of Table 4 by +/- 50%. Then starting from land areas in 1990 also similar to the real English data time series of land areas in each category were generated. The resulting artificial area data are shown in Figure 16-5.

$$\begin{bmatrix} {}_A A_t \\ {}_M A_t \\ {}_U A_t \\ {}_W A_t \\ {}_D A_t \\ {}_O A_t \end{bmatrix} = \begin{bmatrix} {}_{AA}p & {}_{MA}p & {}_{UA}p & {}_{WA}p & {}_{DA}p & {}_{OA}p \\ {}_{AM}p & {}_{MM}p & {}_{UM}p & {}_{WM}p & {}_{DM}p & {}_{OM}p \\ {}_{AU}p & {}_{MU}p & {}_{UU}p & {}_{WU}p & {}_{DU}p & {}_{OU}p \\ {}_{AW}p & {}_{MW}p & {}_{UW}p & {}_{WW}p & {}_{DW}p & {}_{OW}p \\ {}_{AD}p & {}_{MD}p & {}_{UD}p & {}_{WD}p & {}_{DD}p & {}_{OD}p \\ {}_{AO}p & {}_{MO}p & {}_{UO}p & {}_{WO}p & {}_{DO}p & {}_{OO}p \end{bmatrix} \begin{bmatrix} {}_A A_{t-1} \\ {}_M A_{t-1} \\ {}_U A_{t-1} \\ {}_W A_{t-1} \\ {}_D A_{t-1} \\ {}_O A_{t-1} \end{bmatrix}$$

Equation 16-2: Land use change transition or probability matrix. p is probability of transition = fraction of land changing. Each column gives the probability of an area of land e.g. Arable in column 1, changing to a different use. Row 1 gives the probability of land remaining in Arable and each other row gives the probability for the transition to a different use e.g. Arable to Managed Grassland The sum of the probabilities in each column is 1 because all land remains in existence. ${}_X A_t$ and ${}_X A_{t-1}$ area areas of land of type "X" in years t and $t-1$. Subscripts: *A* – Arable land, *M* – Managed Grassland (or Pasture), *U* – Unmanaged Grassland (or Grassland) W – Woodland, *D* – Developed land, *O* – Other land.

From To	Arable	Managed	Unmanaged	Woods	Developed	Other
Arable	0.9650	0.0300	0.0013	0.0000	0.0000	0.0000
Managed	0.0300	0.9390	0.0500	0.0000	0.0000	0.0000
Unmanaged	0.0000	0.0300	0.9427	0.0300	0.0000	0.0000
Woods	0.0050	0.0010	0.0060	0.9700	0.0000	0.0000
Developed	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Other	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Table 16-3. Artificial constant annual probability of land use change between 1990 and 1991 for test purposes and as basis for a matrix with time-varying parameter from 1992-1993 to 2004-2005.

The Bayesian Calibration of a model that assumed that the LUC probability of change matrix varied between each pair of consecutive years independently of any other information was carried out as follows: i. Assume land areas for 1990 are known and the prior probability range of transition values could be represented by multipliers above and below the known artificial transitions, ii. Calibrate transitions using land use data for 1991 as the "Measurements" in the Bayesian method, iii. Repeat for 1991 ->1992, 1992 ->1993 etc. etc. This approach was programmed in Fortran to provide improved computational power over the original Excel calculations. This approach was implemented with MCMC runs of 50,000 iterations per year time step and with different prior ranges for the transition probabilities. The land use area data was assumed to be known very accurately (σ =+/-5 kha) in all cases. Two example results are presented here: A. prior range for transitions probabilities +/-10% of known mean, B. prior range for transitions probabilities +/-50% of known mean. The time series of areas produced from the set of matrices in each case are shown in Figure 16-5. The most likely parameter values from the MCMC process were used to generate model annual land use data. In both examples the model annual land use data track the original data points well. The uncertainty in the model output (as the standard deviation about a mean) for each land type and year is also shown on the graphs but is generally hidden below the data markers in each case indicating an apparently good model. However in Figure 16-6 the variation in the Bayesian calibrated transition probabilities is compared with the know artificial values and it can be seen that a wider prior parameter range allows the calibration to provide better representation of the variation of the parameters. Once again the plotted model parameter values are the most likely from the MCMC and the uncertainty is shown as the standard deviation about the mean from the MCMC.

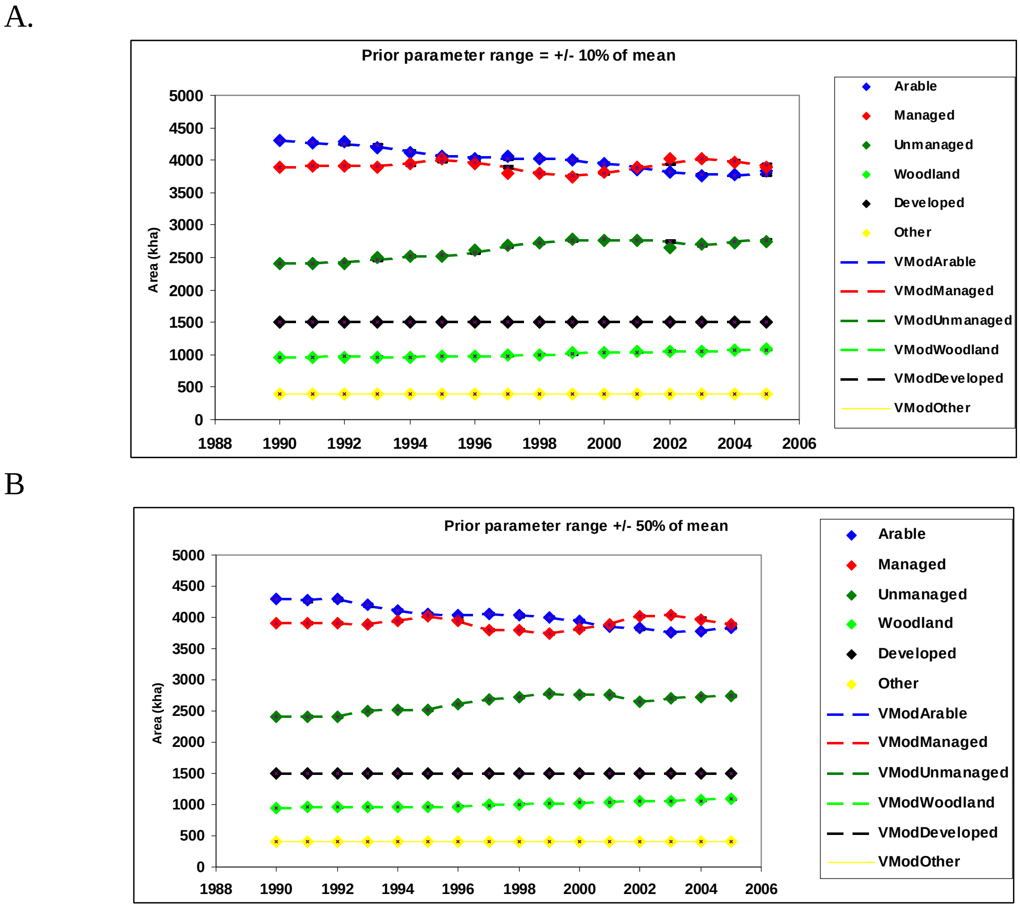

Figure 16-5. Values of land area generated by time varying LUC transition matrix produced by Bayesian calibration using prior transition parameter range of A: +/- 10% and B: +/-50% about known mean artificial matrix compared with areas calculated from the known artificial LUC matrices. Points are original known data and dotted lines follow annual land area from the Bayesian calibrated models

16.8 Enhanced real land use data

The six categories of land for the enhanced analysis using real data are as in test case: Arable, Managed Grass, Unmanaged Grass, Woodlands, Developed and Other. These are shown for England from 1990 to 2005 in Figure 16-7. Data for the other UK countries are available but those for developed land are not available annually outside of England, so some interpolation will be necessary to develop the series for Scotland, Wales and N. Ireland. LUC matrix data to initialise a Bayesian calibration for the six categories is available from the Countryside Surveys for England, Scotland and Wales and from similar surveys in Northern Ireland.

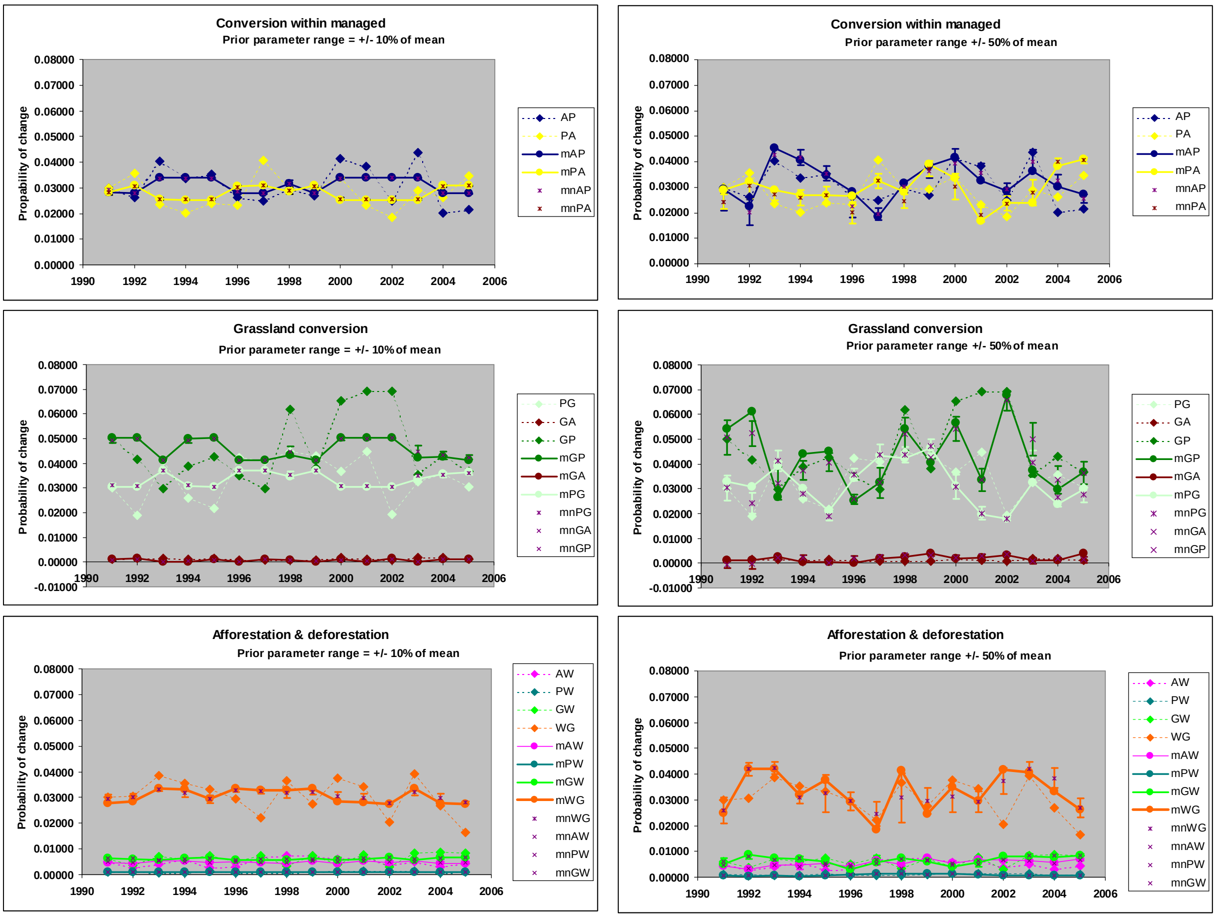

Figure 16-6 Comparison of Bayesian calibrated value of land use transition probabilities compared with true values. Broken lines show true values, solid lines show values from Bayesian calibration. The calibrated values are the most likely from the MCMC samples. Uncertainty ranges for estimated transitions parameters are shown as +/-1σ about the mean value from the MCMC samples. AP – transition from Arable to Managed (pasture), PG – transition from Managed (pasture) to Unmanaged (grassland), AW – transition from Arable to Woodland, etc. etc. Left hand column shows results on assumption of prior range for LUC probabilities of +/-10% about the known mean and right hand column shows results for prior range for LUC probabilities of +/-50% about the known mean.

The approach outlined above for the artificial data was implemented for the six category English data but with the following differences: 1: The real variation in LUC transition probabilities is of course unknown; 2: prior probability ranges for the Bayesian calibration were estimated from the Countryside Survey (CS) 1990 to 1998 data (see Figure 16-7 for the land areas implied by this LUC matrix). The results from two different prior parameter range assumptions are presented here, A: from 0.05xCS value to 5xCS value and B: from 0.05xCS value to 40xCS value. Figure 16-8 shows the time series of land use areas generated from the time-varying matrices from the two different Bayesian calibrations. It can be seen that sufficiently wide prior matrix element ranges have to be used in order to allow the calibration to track the measured data, especially where there were large annual changes in area. As in other figures the model parameter values (and hence annual land use areas) are the most likely from the MCMC and the uncertainty is shown as the standard deviation about the mean from the MCMC.

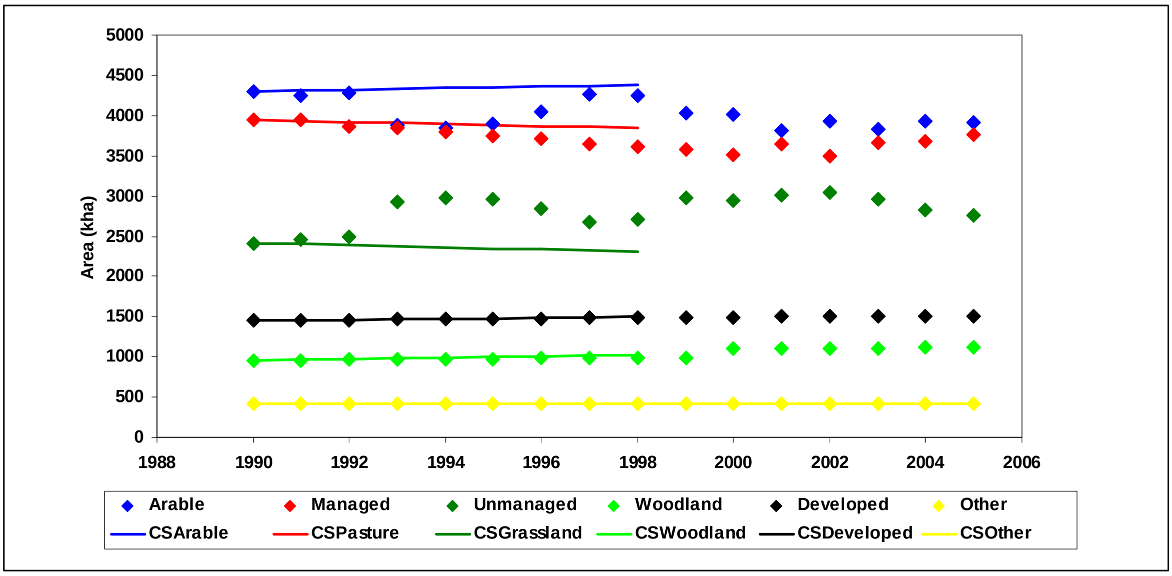

Figure 16-7. Published Land Use data for England for 1990 to 2005 and derived from the LUC matrix of the Countryside Surveys of 1990 and 1998.

The time series of calibrated parameter values (i.e. probability of change elements in LUC matrix) are presented in Figure 16-9 for the two example prior parameter ranges. It can be seen that using a wider prior range allows the parameter values to vary more widely. However except for the better tracking of the annual land use data shown in Figure 16-9 there is no information to assess how well the time series of changing land use change probabilities reflects those of reality. It is true however that the time varying probabilities are likely to be an improvement on those from the assumption of constant LUC matrix.

16.9 Conclusions

The Bayesian approach to estimating time-varying land use changes matrices from annual land use area data has been shown to be a partial success. The approach can provide acceptable results when compared with known test data. The difficulty arises when there is no prior information about the variation with time of land use change probabilities. Such prior information may be available in the form of policy or financial data that would be correlated with changing LUC probabilities. This was illustrated in Figure 16-5.

Future development for the Bayesian approach will therefore require:

Develop relationships between available policy and financial drivers with time variation of parameters presented in this study,

Extend the approach to Scotland, Wales and N. Ireland, which will require development of a method to provide likely ranges of annual data for Developed land in those countries.

Extending the analysis to periods prior to 1990 to provide more information on time variation of LUC probabilities.

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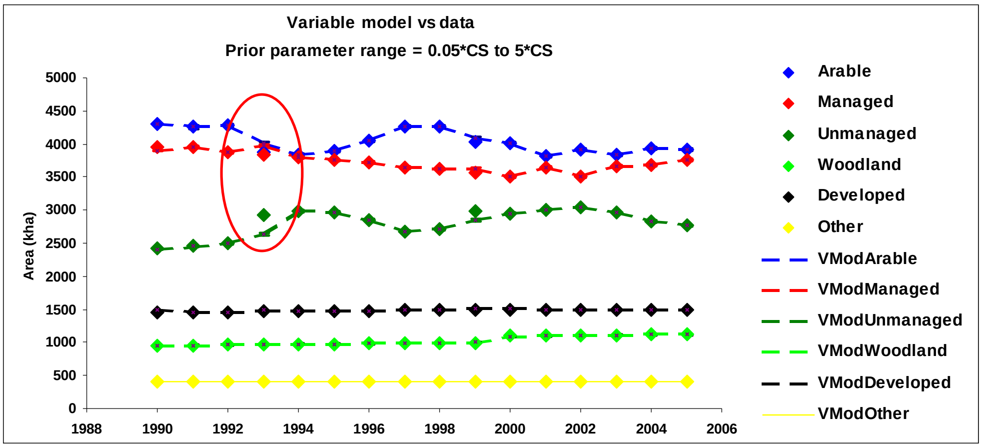

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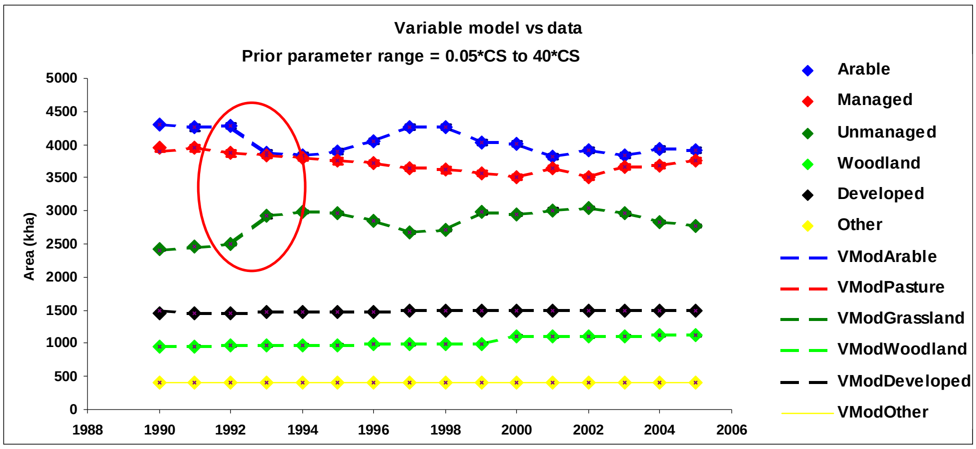

Figure 16-8. Land areas generated by LUC matrix with time-varying probabilities produced by Bayesian calibration. A: Prior probability parameter range from 0.05 to 5 times the Countryside Survey matrix values; B: Prior probability parameter range from 0.05 to 40 times the Countryside Survey matrix values. Improved “fit” to data is indicated where wider prior parameter probability range is used. Points are published annual land use data., dotted lines are follow the output generated from the time-varying land use change matrices.

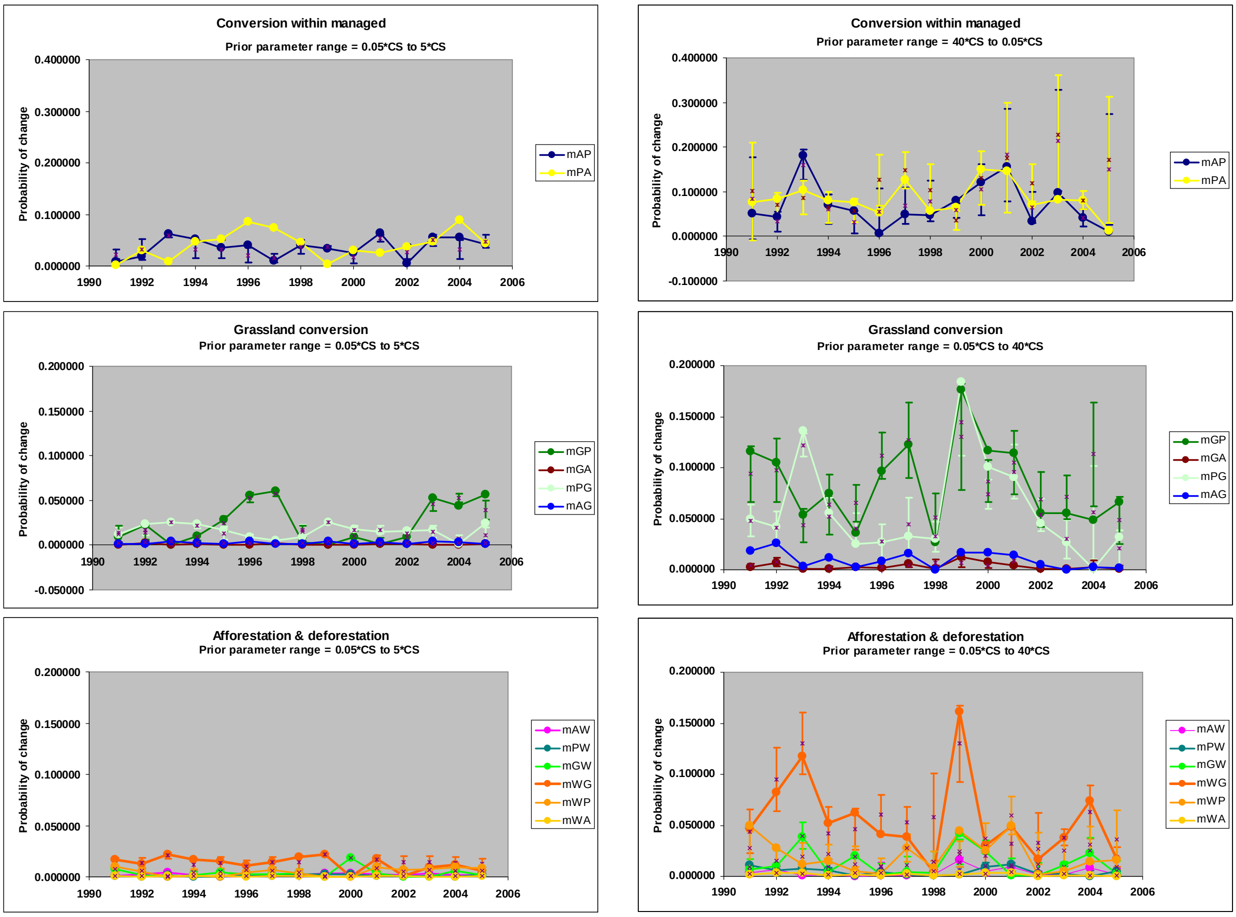

Figure 16-9 Comparison of Bayesian calibrated value of land use transition probabilities for period 1990 to 2005 in England. The calibrated values are the most likely from the MCMC samples. Uncertainty ranges for estimated transitions parameters are shown as +/-1σ about the mean value from the MCMC samples. AP – transition from Arable to Managed (pasture), PG – transition from Managed (pasture) to Unmanaged (grassland), AW – transition from Arable to Woodland, etc. etc. Left hand column shows results on assumption of prior range for LUC probabilities from 0.05x to 5x Countryside Survey LUC matrix values and right hand column shows results for prior range for LUC probabilities from 0.05x to 40x Countryside Survey LUC matrix values.

17. Verification approaches and Design of Greenhouse Gas Observing Systems (WP 2.14 and 2.15)

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17.1 Introduction

In this report we provide estimates of the UK’s biological carbon flux, and sensitivity of sources and sinks to climate change.

The research methodology employed relies on using a simple mass-balance model to infer regional CO_2 exchange. Inputs required for the model include continuous CO_2 concentration measurements at two sites, and information on the prevailing meteorological conditions. This section includes descriptions of the research site locations, including the land cover, topography and climate of the study area, the *in situ* and numerical weather prediction meteorology datasets and the mass balance model itself.

17.2 Research Site Description

Climate

Northern Britain and Scotland in particular, has a temperate, maritime climate, where the air temperature is governed to a large extent by the surface temperature of the surrounding sea. Whilst air temperatures may reach >20°C in the summer months, under moist, south-westerly airflows, January and February are the coldest months, with the daytime maximum temperatures (at low altitude) around 5 to 7°C (UKMO2008b).

Tall Tower Angus

The Angus transmitting station, a 250 m above ground level (agl) telecommunications facility otherwise known as “Tall Tower Angus“, is located at 56.555 ° north latitude, 2.986 ° west longitude, with a tower base height elevation of 318 metres above mean sea level (amsl). A guyed steel lattice mast with faces of three to four metres wide, TTA is located within the Central Lowlands of Scotland, approximately eight kilometres due north from the community of Dundee (population 140,000), and approximately twenty kilometres from the North Sea to the east, south-east.

The tower, located on the south-east corner of a small, elevated plateau, is in an area of low topographical relief with a hilltop to valley elevation change of 100 metres, and undulations between hilltops that vary from several hundred metres to several thousand metres. The non-oceanic landscape within a 350 kilometre radius of TTA (approximately 12 hours flight at mean wind speed) is heterogeneous, comprising primarily pasture grassland (40%), heath, bog and montane habitats (29%), arable cropland (15%) and woodland (9%) (Fuller 2005). The measurement footprint of the 222 metres above ground level instrument height is thought to extend hundreds of kilometres, or further, depending upon the meteorological conditions.

High precision (±0.04 ppmv), high accuracy (±0.1 ppmv) CO_2 mixing ratios were measured by a LI-COR 6252 (LI-COR Inc., Lincoln, Nebraska USA) infrared gas analyser located in a trailer at the base of the tower. The concentrations, pumped down from 222 metres and stabilized at 25 ± 2.5 ^{o}C and 97 ± 13 hPa, commenced in September 2005. Although the CO_2 concentrations were measured every six seconds, the measurements used in the course of this investigation were averaged and output at hourly temporal resolution.

The high precision and high accuracy measurements ere achieved via an inter-comparison against working secondary standards produced by the Max Planck Institute for Biogeochemistry, Jena, which are directly linked with the NOAA Climate Monitoring and Diagnostics Laboratory primary standards (Manning 2004). These reference measurements were accomplished four times a day, with the secondary tanks regularly circulated between participants within the European tall tower network (Chiotto: http://www.chiotto.org/) to ensure intra-tower comparability. Every two weeks, the concentrations of two long-term secondary cylinders are also measured in an effort to detect and offset drift of the instrument sensors.

The CO_2 measurements are thus of a very good standard, with no significant filtering of the time series being required. Small data gaps in the CO_2 time series, of three hours duration or less, were filled-in via linear interpolation.

Griffin flux tower

Griffin Forest (56.607 ^{o}N, 3.797 ^{o}W, 340 m amsl) is a long-term research measurement site located within a Sitka Spruce (*Picea sitchensis* (Bong.) Carr.) plantation, 50 kilometres due west of Tall Tower Angus, in the Grampian Mountains of central Scotland (*cf*. Figure 17-1). A 20 metre, micro-meteorological tower has used eddy covariance methods to determine the instantaneous flux of carbon dioxide, water vapour, and energy between terrestrial ecosystems and the atmosphere at Griffin since 1997.

Mace Head

Located on the west coast of Ireland (53.333 ^{o}N, 9.900 ^{o}W), the atmospheric research station at Mace Head (MHD) is uniquely exposed to the mid-latitude cyclones which frequently traverse the north Atlantic. As such, it affords the opportunity to investigate atmospheric composition under ”clean”, northern hemisphere background conditions and is consequently one of the baseline stations of the World Meteorological Organisation’s Global Atmosphere Watch network (Miller 1997).

The CO_2 concentration measurements, which have been continuously measured at MHD since 1992 (Biraud 2000; Derwent 2002), are methodologically filtered and smoothed to produce a baseline time series presumed to be representative of the northern hemispheric background signal (Manning 2008).

Meteorological data sets

Three separate meteorological datasets were used in the course of this research, the *in situ* measurements at TTA, regular, airborne measurements above Griffin (”Aerocarb”) and a UK Met Office numerical weather prediction (NWP) meteorology dataset.

In addition to the measurements of trace gas concentrations, atmospheric pressure, air temperature and relative humidity were measured at ground level, near the base of the tower, and at 50 m, 100 m and 200 m above ground level, along the tower mast.

Regular vertical aircraft sampling in the lower troposphere above Griffin has been performed since 2001 (Sturm 2005). Working in association with CarboEurope's Aerocarb project (the Airbourne European Regional Observations of Carbon Balance: http://www.aerocarb.cnrs-gif.fr/), the approximately monthly flights provide *in situ* measurements of atmospheric pressure, temperature, relative humidity and flask-measured trace gas concentration at regular intervals up to three kilometres altitude (visibility permitting).

As TTA lacks pressure, temperature and relative humidity measurements throughout the height of the atmospheric boundary layer, meteorological data were obtained from the UK Met Office's Unified Model 6 (UM6) (Staniforth2004). Designed to be useful to both numerical weather prediction (NWP) and climate modelling applications, the meteorological fields supplied to us by the Atmospheric Dispersion Group comprised the T+6 hour forecasts for the three-dimensional mesoscale (12 kilometre horizontal spatial resolution, 32 level variable-height vertical resolution up to 19 kilometres, 1 hour temporal resolution) domain, from which meteorological values for TTA are interpolated.

Atmospheric boundary layer height is also a meteorological field stored within the UM6 meteorological dataset. Based on the bulk Richardson number being approximately unity (Brown 2008), the atmospheric boundary layer height is significantly more uncertain than the pressure, temperature and relative humidity estimates.

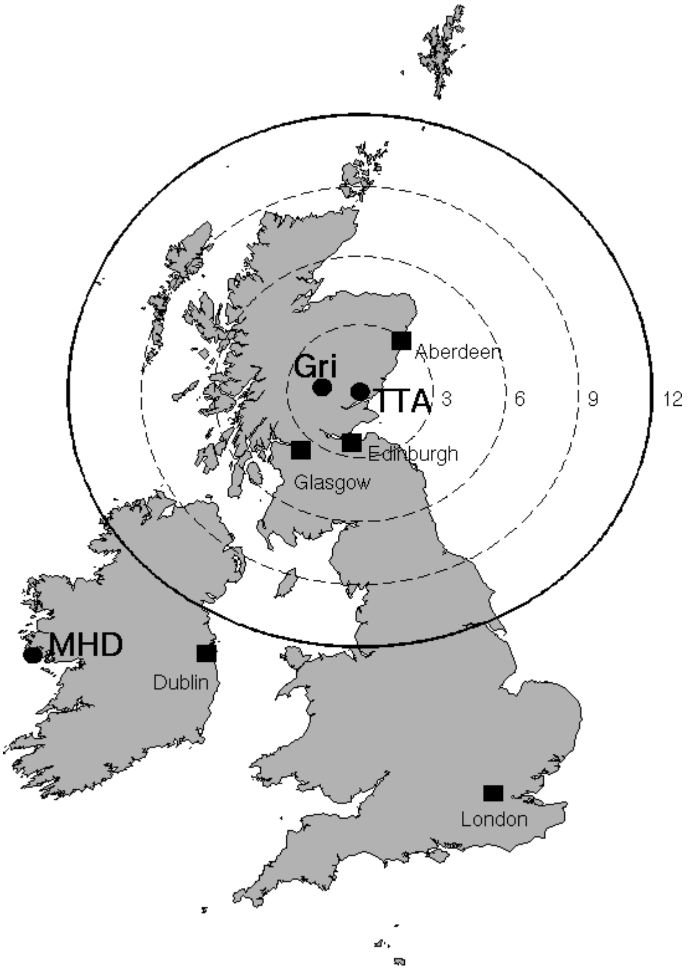

Figure 17-1. Locations of the base-line station at Mace Head (MHD), Tall Tower Angus (TTA) and Griffin Forest (Gri). The concentric circles represent the approximate distance an air parcel would travel, at mean measured wind speed (3.8 m/s), at six, 12, 18 and 24 hours intervals.

Mass balance model

In order to estimate the amount of carbon dioxide exchanged between the atmosphere and the land surface throughout northern Britain, a simple mass balance model was constructed. Utilising a virtual volume, the model assumes the net regional exchange in CO_2 for northern Britain ($F_{Exchange}$, in µmol m^{-2} s^{-1}) may be approximated by considering the CO_2 entering and leaving the enclosed volume.

$$F_{Exchange} = F_{Out} - F_{In} \pm F_{Entrainment} \pm F_{Chemistry} \qquad (1)$$

where F_{Out} is the CO_2 flux which leaves the volume, F_{In} is the CO_2 flux which enters the volume, $F_{Entrainment}$ is the entrainment flux, that exchanged with the Free Troposphere, and $F_{Chemistry}$ is the rate of change of CO_2 due to chemical conversion.

To simplify the problem somewhat, and as the atmospheric lifetime of CO_2 (> 5 years (Albritton 2001)) is significantly longer than the timescale for an air parcel to cross northern Britain (~9 hours are mean wind speed), $F_{Chemistry}$ can be set to zero. Furthermore, and to exclude the possibility of pollution events from continental Europe biasing the result, the model retains west-to-east winds only.

Thus, F_{Out} becomes the flux leaving the volume out the eastern boundary, which we will assume may be represented by that measured by Tall Tower Angus (F_{TTA}), and F_{In} becomes F_{MHD}, the flux entering via the western boundary, as measured by Mace Head:

$$F_{Exchange} = F_{TTA} - F_{MHD} \pm F_{Entrainment}. \qquad (2)$$

Provided the atmospheric boundary layer is well mixed and the CO_2 concentration of the Free Troposphere may be represented by Mace Head, the individual components of the boundary layer budget calculation are therefore:

$$F_{TTA} = \int \int u_{TTA}(y,z)\, C_{TTA}(y,z)\, dy\, dz, \qquad (3)$$

$$F_{MHD} = \int \int u_{MHD}(y,z)\, C_{MHD}(y,z)\, dy\, dz, \qquad (4)$$

$$F_{Entrainment} = \int \int w(x,y)\, (C_{TTA} - C_{MHD})\, (x,y)\, dx\, dy. \qquad (5)$$

where C_{TTA} is the measured CO_2 concentration at Tall Tower Angus, C_{MHD} is the CO_2 baseline concentration at Mace Head, u is the NWP wind speed at TTA at 225m agl and w is the vertical component of the NWP wind speed at the base of the Free Troposphere.

Finally, assuming spatially uniform and constant wind speed and wind direction, throughout the ABL, the net regional exchange may be approximated as:

$$F_{Exchange} = \left(\frac{(C_{TTA} - C_{MHD})}{m_{air}\, l} \right) (\rho_{TTA}\, u_{TTA}\, z_{ABL} \pm \rho_{FT}\, w\, l) \qquad (6)$$

where z_{ABL} is the NWP height of the atmospheric boundary layer, ρ_{TTA} is the CO_2 air density at 225 m agl at TTA, ρ_{FT} is the CO_2 air density of the Free Troposphere (the mean of that above the ABL height up through three kilometres), w is the vertical component of the NWP wind speed at the base of the Free Troposphere, m_{air} is the molecular mass of dry air and l is the west-to-east mixing length, the distance in kilometres of TTA to the Atlantic Ocean in the direction of the instantaneous NWP wind direction.

To allow as correct a calculation as possible, a sixth-order saturated-vapour pressure equation (Flatau 1992) was used to calculate the dry CO_2 abundance, for better agreement with the CO_2 concentration measurements, which are measured with all the water vapour removed.

17.3 Results

Climate

2006 was the warmest year since records began in 1914 at 8.25°C, resulting from higher than average summer and autumn temperatures (Figure 2). Despite November and December 2006 being the wettest months recorded, it was a moderately dry year, with less than average precipitation and significantly more than average sunshine.

2007 was the third warmest year ever recorded at Leuchars (8.18 °C), and the second warmest recorded for the UK, despite rainfall in the summer months exceeding the average for this time of year (Figure 17-2). This was due to average air temperatures in the spring and winter months being significantly higher than normal. 2007 was also remarkable for its overcast skies, with relatively low levels of global solar irradiation.

Although higher than average air temperatures continued into 2008, with January and February being more than 1 °C warmer than the long-term average for these months (Barrow 1993; Perry 2005), by December, the air temperature was more than half a degree colder than the long term average. Eastern Scotland also experienced the second wettest year ever in 2008, with record amounts in January, April and August.

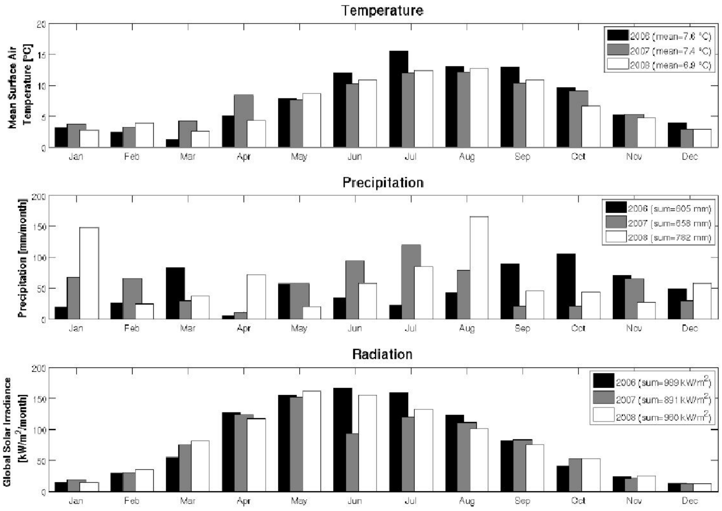

Figure. 17-2. Meteorological data for 2006 (upper), 2007 (centre), 2008 (lower).

Concentrations

As many of the eastern winds are associated with measurements in excess of expected diurnal behaviour, gas concentration measurements from the East are removed such that only 47% of the original TTA CO_2 hourly concentrations remain after accounting for data gaps, wind direction and invalid measurements.

The variability of the concentration measurements (Figure 17-3), easily visible at all temporal scales, is highly dependent upon both the local meteorological conditions and the associated ecosystems underneath. Overplotted the TTA time series in Figure 17-3, are the heavily filtered and smoothed CO_2 concentrations from Mace Head. As in Messager *et al.*., 2001, the filtering of the MHD dataset resulted in a smoothly-varying representation of the background CO_2 level such that the difference between the two time series strongly determines the calculated surface-atmosphere exchange flux for the observation volume.

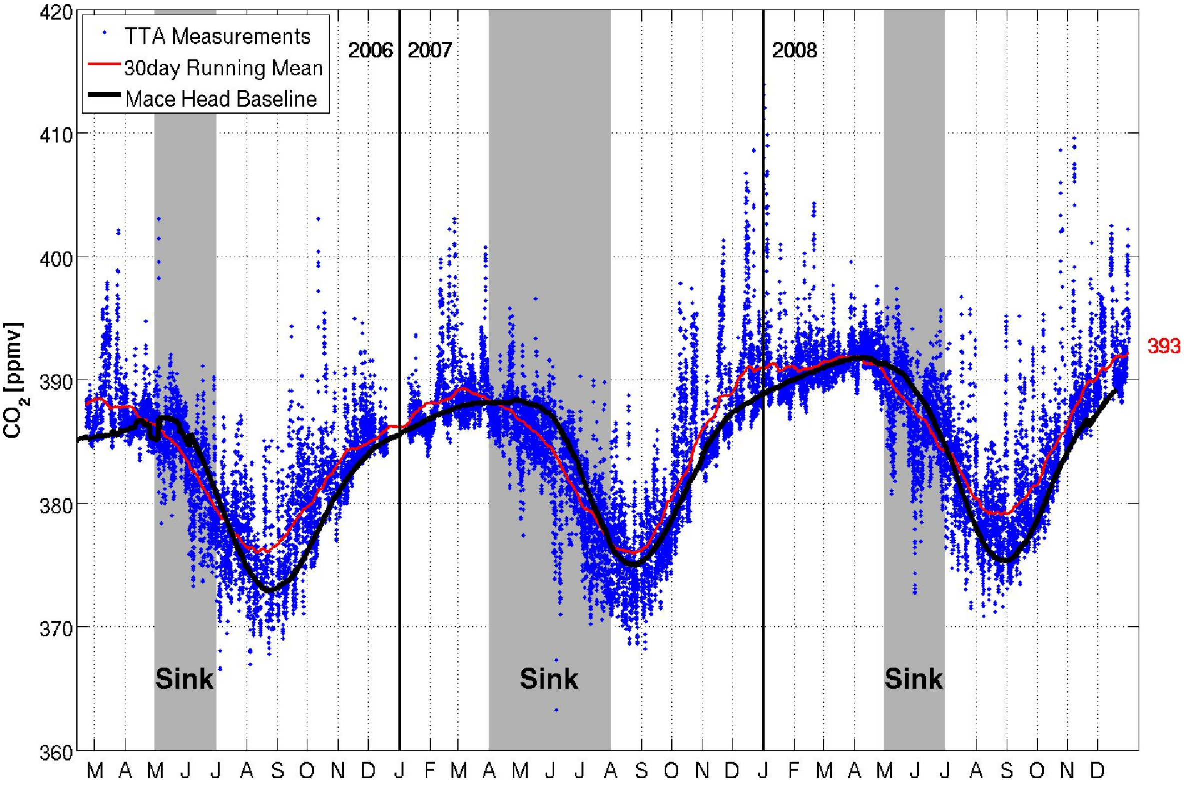

Figure 17-3. Concentrations of CO2 at Tall Tower Angus and the 30 day running mean at Mace Head, for years 2006, 2007, 2008.

Fluxes

The calculated regional fluxes of CO_2 show a seasonal pattern, with net uptake in the summer period, and carbon losses in the winter (Figure 17-4). Fluxes at the Griffin forest, although representing an area of order only 1 km^2 , show some general similarity to the regional fluxes (Figure 5).

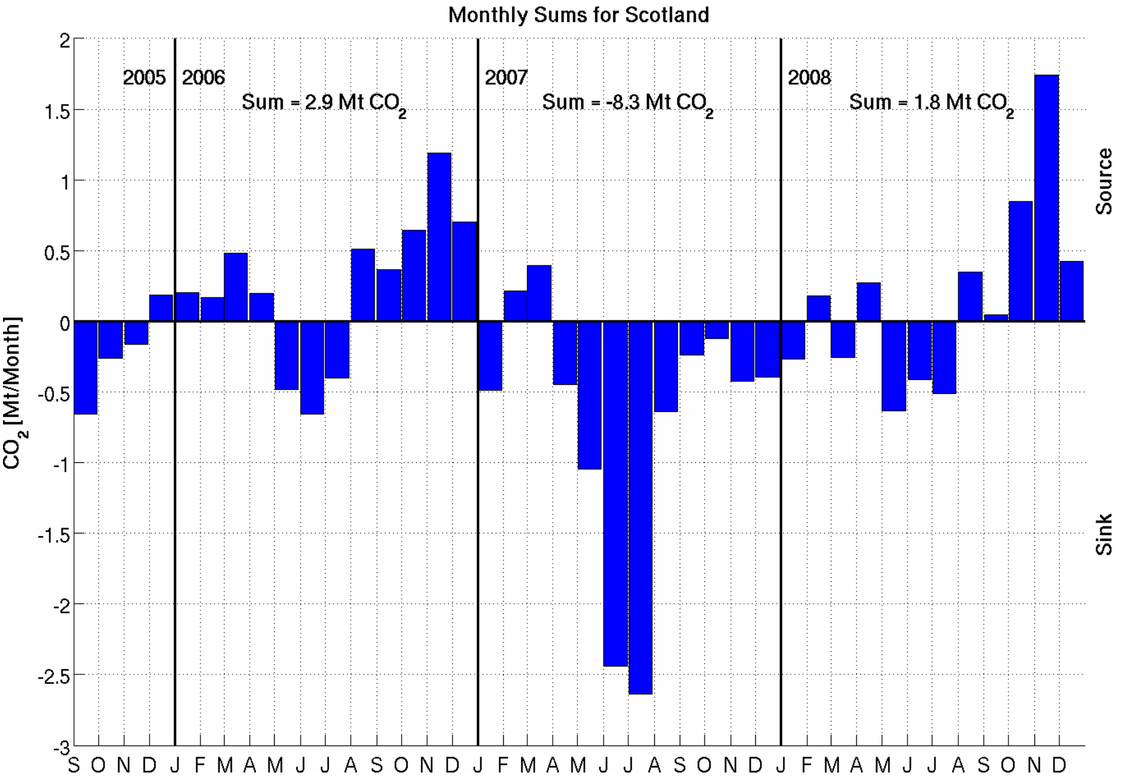

Figure 17-4. Monthly CO_2 fluxes calculated from Figure 3.

A simple cross-correlation analysis suggests a lag of five hours which at average wind speed, is approximately the distance between TTA and Griffin. The minor discrepancies in the two time series is thought to be due to the different ecosystems underlying the two landscapes (evergreen forest for Griffin and the regional Scottish landscape for TTA, including urban and industrial sites). We assume that the processing of the MHD dataset produces an unbiased result.

Overall, the mean calculated flux from TTA was -0.3 μmol m^{-2} s^{-1} (negative denoting uptake) for 2006-2008 with a maximum day-time net regional exchange of -30.2 μmol m^{-2} s^{-1} during the most active phase of the summer (May to August). Mean night-time respiration was approximately 0.1 μmol m^{-2} s^{-1}, while the typical net regional exchange during the dormant season (December to February) was -0.1 μmol m^{-2} s^{-1}. The seasonal pattern of net regional exchange of CO_2 was highly correlated with leaf-out and leaf-fall, and soil thaw and freeze. On average, the landscape within the fetch of Tall Tower Angus absorbed approximately 8.7 g CO_2 m^{-2} day^{-1} during the growing season.

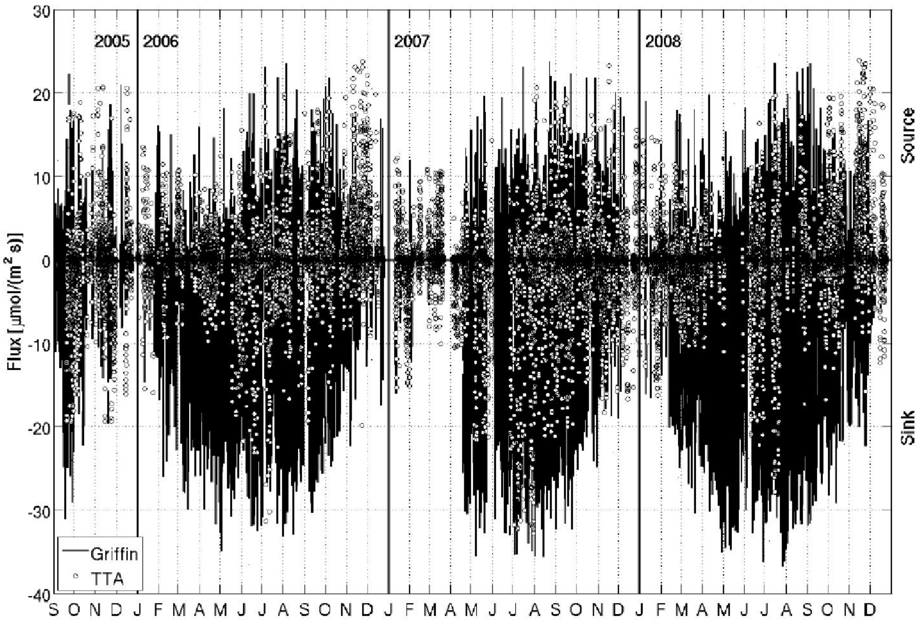

Figure 17-5. High time-resolution fluxes from Tall Tower Angus (dark lines), overplotted with data from Griffin Forest (open circles).

The budget calculation is sensitive to a number of assumptions. Foremost among these is the assumption that selection of western winds do not introduce a bias. The eastern winds are excluded from this analysis because the signals from the east contain episodic emission events, resulting in a noisy signal which is harder to analyse, and represents emissions outside the UK. It seems unlikely that a bias is introduced by selecting only western air flows.

Although the meteorology (including ABL height) exerted an insignificant role in the variability of the estimated exchange (less then 0.5%), with a standard deviation one-quarter the value of its mean, the west-to-east fetch (that is, the distance over land the virtual air parcels travel) is one of the most uncertain variables in the mass balance budget determinations. It also exerts a significant influence on the calculated variability. Owing to its proportionally large influence on the size of the virtual volume, small variations in the fetch (standard deviation = 40 kilometres), produce large variations in net regional exchange (up to 400% if the three years are combined into a single representative year). As the difference between the TTA and Mace Head CO_2 concentration time series establishes the scale of the calculated exchange, it is of little surprise that calibration uncertainties should also produce a pronounced influence on the resulting estimates. Utilising the estimated respective uncertainties, small errors in the absolute calibration can be to seen to exert large uncertainties in estimates of net regional exchange by tall towers, emphasising the need for rigorous calibrations in the future.

Analysis of the corresponding data for CH_4 and N_2O is in progress, and here we show the fluxes of methane, averaged over the three years to produce a more robust result (Figure. 17-6). There is an apparent seasonal pattern, with more land-to-atmosphere flux in the winter, spring and early summer, possibly reflecting the high level of the late-winter water table over the broad region, and therefore the degree of anaerobic respiration required to produce methane.

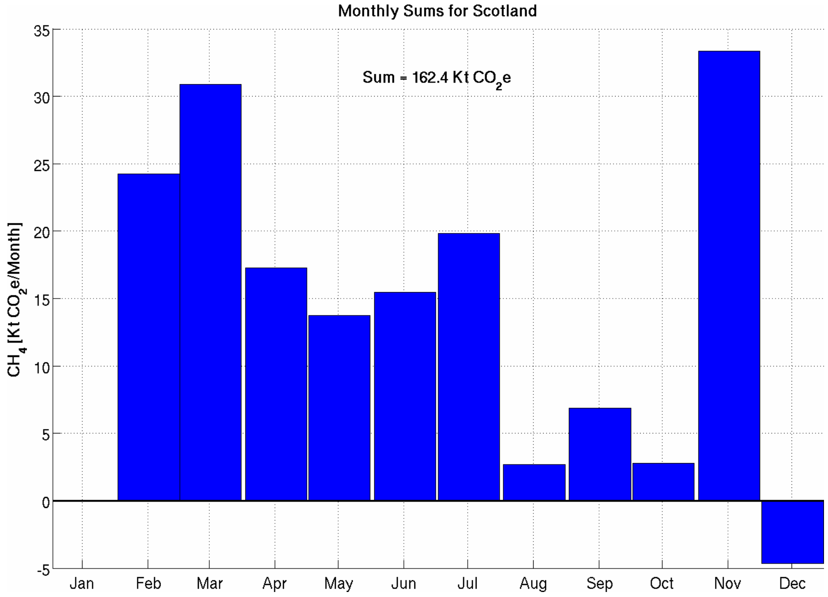

Figure 17-6. Monthly fluxes of methane, averaged over three years. Flux units have been converted to CO_2 equivalent.

Table 17-1. Summary of the annual data, obtained from the Tall Tower Angus. According to the National Inventory, Scotland is a source of 44 Mt CO_2 and CH_4 is a source of 5 Mt CO_2equivalent (Jackson *et al.* 2008). For an explanation of this difference, see the Discussion.

	2006	**2007**	**2008**	**2006-8**
CO_2 (Mt CO_2/year)	2.9	-8.3	1.8	-0.2
CH_4 (Mt CO_2 eq./year)	Not robust	Not robust	Not robust	+0.16

17.4 Discussion

The most striking feature of the CO_2 flux data is the indication of a moderate net sink in the summer months, co-incident with the major period of carbon uptake by vegetation. This is not as expected from the national inventory data, which are dominated by the anthropogenic flux. Taken at face value, these data imply the presence of a biological sink so strong that it largely cancels out the anthropogenic flux. For this to be the case, the biological flux density averaged over Scotland and over all seasons would need to be 0.4 µmol m^{-2} s^{-1}. This is not an impossible figure: forest plantations averaged over a plantation's lifetime in this part of the UK are typically 3 ton C ha^{-1} $annum^{-1}$ (Magnani *et al.* 2007), which, when expressed in different units, is 0.8 µmol m^{-2} s^{-1}. Semi-natural vegetation is likely to be considerably less than this, of course. On the other hand, the clear seasonal signal and the similarity between the tall tower result and the fluxes measured over a distant forest, suggest that biological sinks are much more active than has been realised and are indeed of the same order of magnitude as the fossil fuel emissions.

In fact, rather little is so far known on the carbon dynamics of the other forms of land use that are so extensive in this part of the UK. Although long term measurements on peat lands have been started (particularly in Nordic countries), they are in their infancy in the UK. However, the overall statistics of peat-lands have been known for some time: Gorham (1991) estimated that boreal and subarctic peatlands accumulate 0.076 Pg of carbon annually, over an area of 3.5 million km2, corresponding to a biological sink strength of 0.58 µmol m^{-2} s^{-1}. Thus, it seems not unlikely that it is this semi-natural vegetation on peatlands, combined with a high plantation coverage, that makes the northern part of Britain approximately carbon neutral. Such vegetation might indeed be expected to exhibit its strongest sink in wettest years, which is what is in fact observed. Only longer term measurements combined with direct flux measurments will show us whether this conclusion is valid.

Although the concentration footprint of the tall tower does include parts of the UK outside Scotland, much of the landscape of northern Britain and Ireland is similar in composition, with substantial areas of semi-natural vegetation including moorland and rough grazing on organic (peaty) soils, and extensive agriculture with forest plantations. Sometimes the footprint includes Glasgow, Edinburgh and the central belt, where most people live and most industrial activity takes place, but often the wind direction is different and it does not. There may well be under-sampling of these densely populated and industrialised areas.

On the other hand, the clear seasonal signal and the similarity between the tall tower result and the fluxes measured over a distant forest, suggest that biological sinks are much more active than has been realised and of the same order of magnitude as the fossil fuel emissions. .

Organic soils have accumulated carbon stocks through being a carbon sink over periods of thousands of years, and Scotlands peatlands

Nor can the possible error of calibration of the IRGAs between Mace Head and Tall Tower Angus, or the uncertainty in the height of the planetary boundary layer, account for the difference. Most likely the discrepancy results from the nature of the tower's footprint: although it 'sees' the whole of Scotland (and beyond), the landscape within 50 km influences the air mass arriving at the tower to a greater degree than more distant landscape, so that the overall result is essentially weighted more strongly to a local area. To overcome this difficulty, it will be necessary to refine the analysis method, relying not on the box model but on a trajectory analysis. In this approach it will be necessary to consider trajectories on an hour by hour basis, and apply a weighting factor to allow for the probability that the air is influenced by the landscape at a series of distances from the tower. Another way to overcome this difficulty is to work with a network of towers, using a description of the land surface in a transport model, and using an inversion approach as has been discussed elsewhere (Rayner and O'Brien 2001, Geels *et al.* 2007). Aircraft flights can provide useful information (Polson 2008), although they suffer from the same type of sampling problem *plus* they can only ever sample on a fraction of all days of the year.

Similar remarks apply to the calculated methane fluxes (which are much smaller than those expected from the national inventory). The net biogenic methane emission is likely to be influenced by emissions by wetlands but agricultural land and semi-natural land surfaces are known to be sinks for methane, as a result of activities of the methanotrophic bacteria, particularly in upland soils (reviewed by Dunfield 2007).

Finally, we make some remarks about the general task of verifying national greenhouse gas inventories by reference to atmospheric concentrations of gases. The inventories do not capture sources and sinks which are associated with natural biological processes. Rather, through land use inventories, they attempt to capture the extent of change-from-a-baseline that is brought about by human activities. For most countries, the carbon fluxes associated with land use change are rather small in relation to the GHG emissions, for example in the UK as a whole the carbon emissions are of order 160 Tg per annum whilst Land-use Change and Forestry, including estimated changes in forest biomass, crop biomass, peat extraction and soil changes due to land use change, liming and drainage, amount to only 2-3 Tg per annum. Given that the resulting CO_2 from LULUCF is not distinguishable from the much larger overall biological fluxes, it is unlikely that a network of tall towers alone will ever be able to measure the LULUCF component of the national carbon budget. It would however be able to assist in ‘full-greenhouse gas accounting’ by providing monthly and annual totals.

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18. Soil Carbon in Northern Ireland: Using the Tellus Survey's Gamma-Ray dataset to delineate the extent and depth of peat in Northern Ireland (WP2.16a)

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18.1 Introduction

The Tellus Project, managed by the Geological Survey of Northern Ireland (GSNI), has produced a series of new geochemical and geophysical maps to extend and deepen our knowledge of the geology, soils, natural resources and environment of Northern Ireland and provides a country-wide environmental baseline. Full details of the Tellus project, including a map viewer, can be found at: http://www.bgs.ac.uk/gsni/tellus/index.html.

The British Geological Survey (BGS), in partnership with the Geological Survey of Finland (GTK), flew a low-level airborne geophysical survey over the country in 2005–6. The survey aircraft, one of several scientific aircraft owned by NERC, flew a total distance of 86,000 km at a height of 56 m and collected magnetic field, electrical conductivity and terrestrial gamma-radiation measurements. The results have provided new insights into Northern Ireland's geology, particularly where bedrock is obscured by glacial cover and peat.

18.2 Method

All rocks and soils are very slightly radioactive and it is possible to detect their background radiation using a gamma-ray (φ) spectrometer in a low-flying aircraft. Most terrestrial radiation arises from isotopes of uranium, thorium and potassium and the proportions of these vary by rock type (Figure 1). Mapping natural radioactivity is, therefore, another useful means of differentiating rock and soil types. It was observed that areas covered by peat had much reduced activity and this fact has been investigated as a means of delineating the extent and depth of peat across the Province (Figure 18-1).

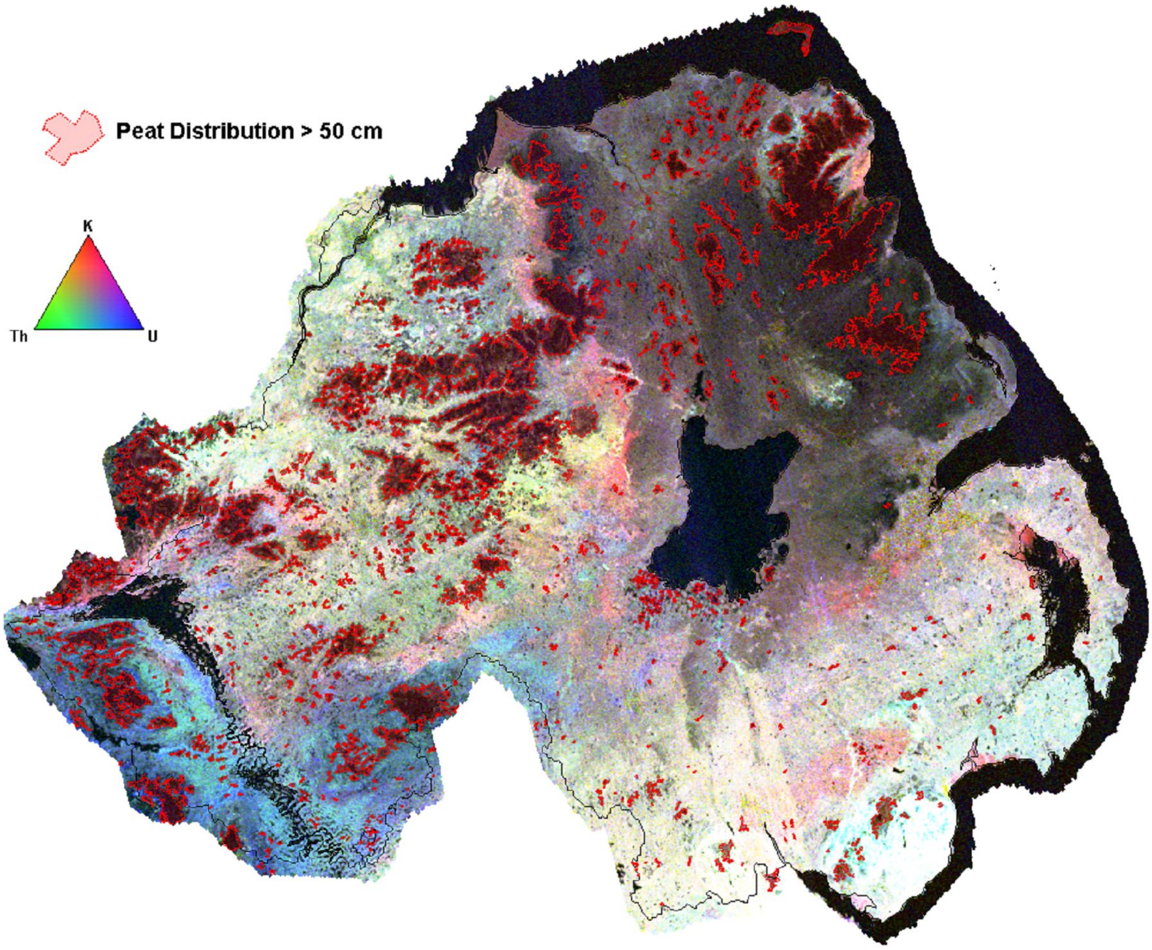

Figure 18-1. Ternary map (U-Th-K) of natural radioactivity for Northern Ireland from the Tellus survey overlaid with peat extent. Topographic data based upon Ordnance Survey of Northern Ireland's data with the permission of the Controller of Her Majesty's Stationary Office, © Crown Copyright and database rights MOU205.

Peat is essentially a hydrocarbon and is usually relatively free of the natural occurring radioactive elements (K, U, Th). In contrast to soils or rocks, peat *absorbs* rather than *emits* φ-rays and can thus acts as a radiation shielding material. As a result, we would expect that the thicker the peat, the lower the observed background radiation count rate should be. This is the basis for using the Tellus radiometric data to map peat thickness.

If peat absorbs the natural radioactivity (φ-rays) from the underlying rock formations, and φ-ray attenuation follows the exponential law, then

$$N = N_o e^{-\mu x}$$

where N = measured φ-ray count rate, N_o = original (background) φ-ray count rate, x = the thickness of the medium the φ-rays are passing through and μ is the absorption coefficient of the medium.

18.3 *Results and Discussion*

As a first assumption, the count rate halves every time the peat thickness doubles. The Sperrin Mountains area, underlain by Dalradian schists, was found to have a background count rate of about 2400 cps (counts per second). By matching up the AFBI peat map (peat depth >50cm) from the AFBI soil survey with the contoured radioactivity data, it was observed that the peat extent matched the 1200 cps contour (Figure 18-2). It was assumed that lower counts were due to deeper peat. Using the assumption above, if the count rate is 1200 cps for peat 50 cm deep, then at 600 cps the peat is 100 cm deep, at 300 cps 200 cm deep, etc.

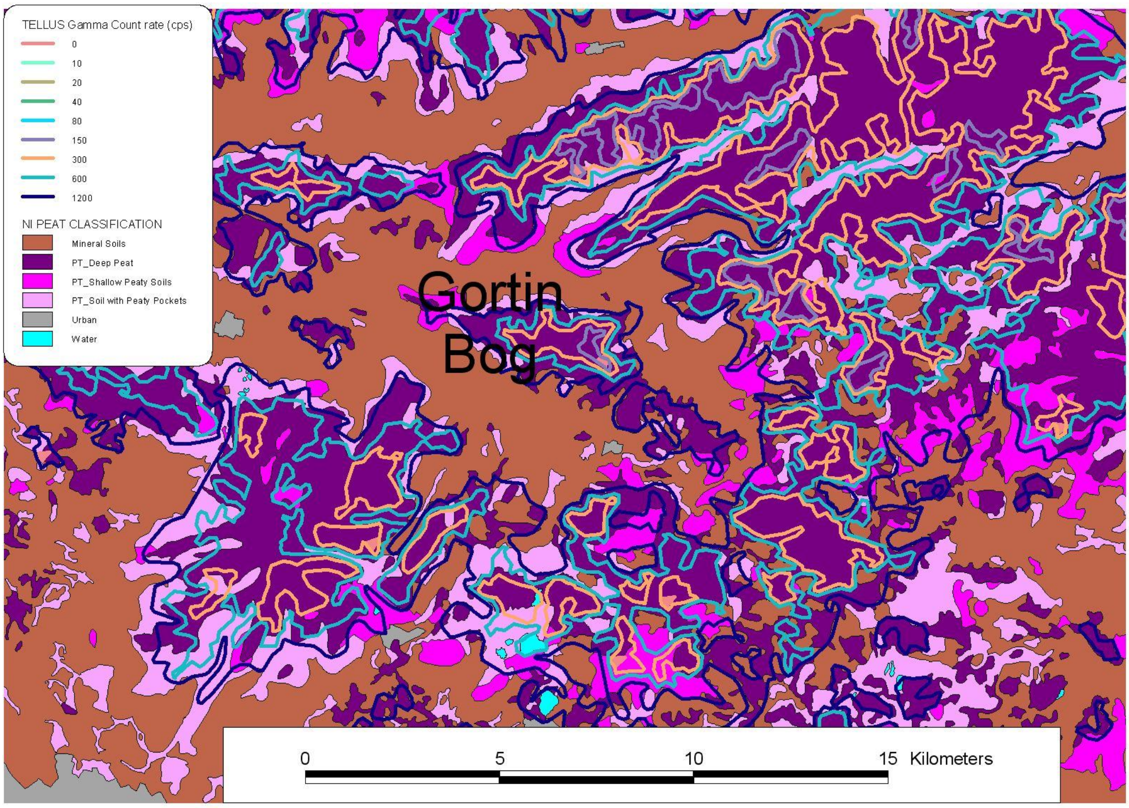

Figure 18-2. Tellus gamma-ray counts for the area around Gortin Bog (Sperrin Mountains).

Different geologies were found to have different limits. Thus, on the Antrim plateau (basalt geology), blanket peat extent corresponds to the 300 cps contour (>50 cm deep), 150 cps to 100 cm deep etc (Figure 18-3). However, the 1200 cps contour contained all peaty soils (including shallow peats (<50cm)) regardless of geology across Northern Ireland and so this contour can be used to delineate the full extent of peaty soils. Using the φ-ray contours, the extent of peat in Northern Ireland was estimated to be approximately 1,550 km^2. This compares to the mapped peat extent of 1,927 km^2 based on the AFBI soil map for Northern Ireland.

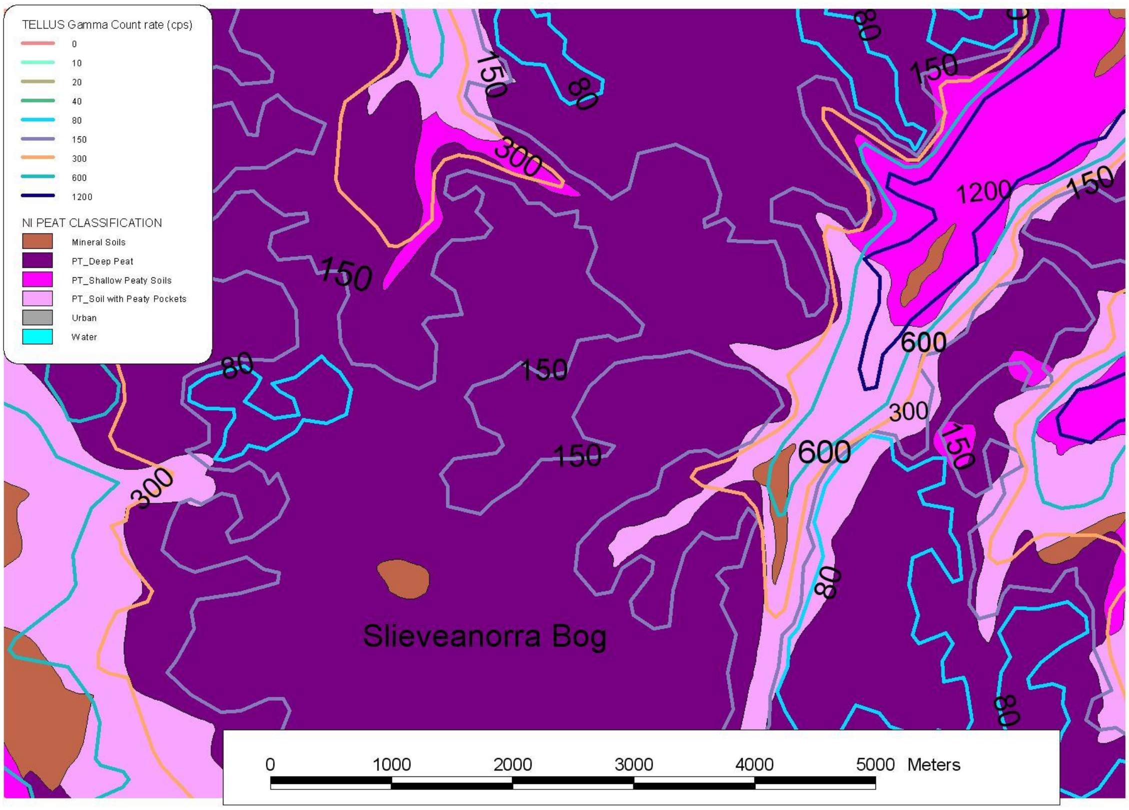

Figure 18-3. Tellus gamma-ray counts for the area around Slieveanorra Bog (Antrim plateau).

Field work carried out with the Queen's University of Belfast (QUB) showed a good correlation between the airborne φ-ray count rate and peat depth in Gortin Bog (Sperrin Mountains) (Figure 18-4) where the φ count rate dropped to ~200 cps at peat depths around 1.5m. Based on the observed φ-ray attenuation, peat in this area had an absorption coefficient of 1.37. A similar relationship was confirmed by AFBI in nearby Black Bog for peat depth <~3m (peat depth and bulk density data reported on last year).

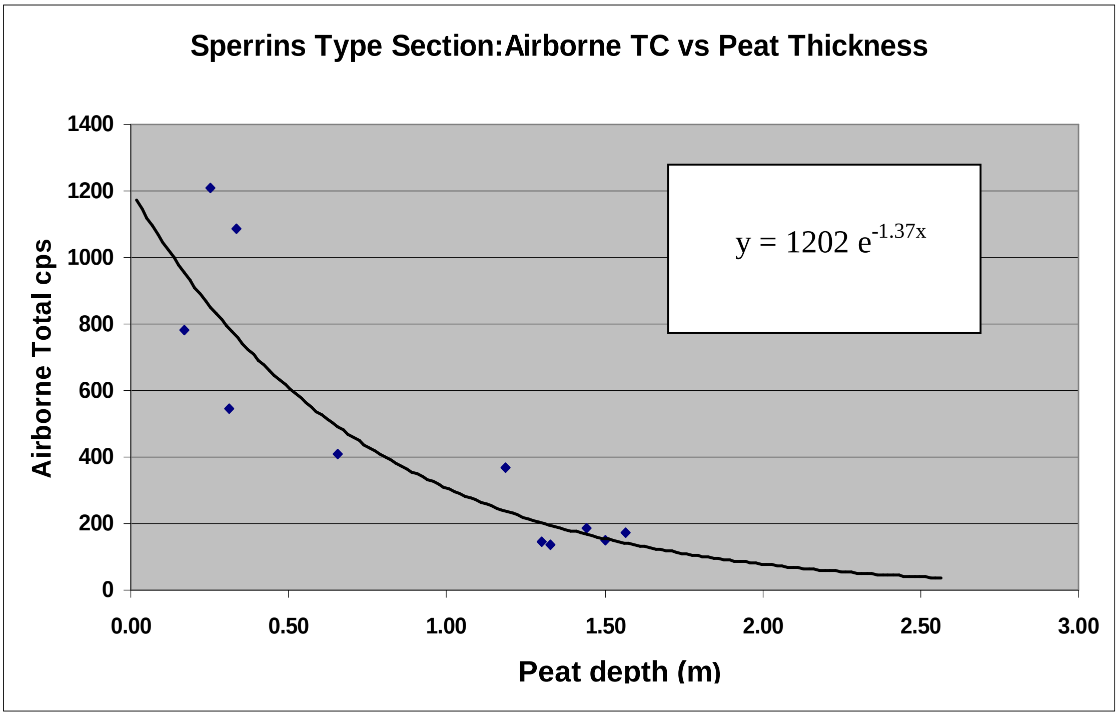

Figure 18-4. Tellus *φ*–ray count rate vs measured peat depth for Gortin Bog (Sperrin Mountains) with fitted exponential trendline and equation.

Similar work in a deeper peat bog (Slieveanorra Bog, Co Antrim, NE; peat depth up to 6m; peat depth and bulk density data reported on last year) using peat depth data from the NI Peatland Survey 1988 gave a much poorer relationship, which was statistically not significant (Figure 18-5). In this part of Slieveanorra Bog, the φ count rate (around 200 cps) was virtually independent of depth (nearly all depths were greater than ~2m) i.e. this method may not be able to discriminate peat depths over 2m.

Comparisons for the other major geologies (shales and granites in Co Down (SE) and sandstones and limestones in Co Fermanagh (SW) have not yet been made but the comparison between Slieveanorra and Gortin Bog (Co Tyrone, NW) suggests that this approach, using the aircraft data, may be limited to measuring peat depths less than 2m. However, there are indications from field work carried out by QUB staff that using a more sensitive, field-based φ-spectrometer may lead to better estimates of peat depth for depths >2m.

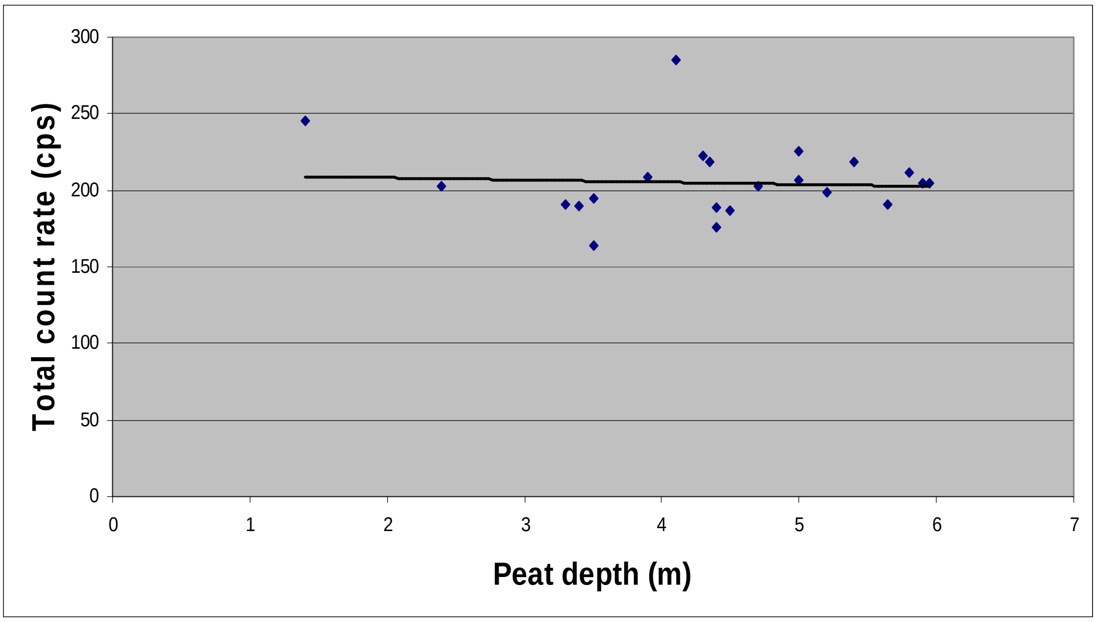

Figure 18-5. Tellus *φ*–ray count rate vs measured peat depth for Slieveanorra Bog (Antrim Plateau) with fitted exponential trendline (not significant).

18.4 Conclusion

This work has shown the potential of the Tellus geophysical dataset to map peat extent and depth for peat <2m deep. It has also demonstrated that the relationship between total φ count rate and peat depth in each major geological area must be separately calibrated.

This potential will be explored further in future QUB MSc and/or PhD projects when it is expected that AFBI data on changes of peat bulk density with depth will be integrated with peat depth estimates derived from both the Tellus survey and estimates generated from a φ-spectrometer in the field, to derive an updated carbon inventory for Northern Ireland.

19. Carbon losses due to peat extraction in Northern Ireland (WP 2.16b)

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19.1 Introduction

In the late 1980s, concern about disappearing peatland was common in Northern Ireland, particularly the loss of peat caused by the apparently widespread expansion of mechanized extraction of peat for fuel. Concern about this extraction stimulated research on the extent of all forms of peat extraction, on physical and socio-economic factors and interactions that help explain that extent (Cruickshank et al., 1995), and into the environmental effects of peat extraction (Bayfield et al., 1991; Todd, 1995).

In the 1990s, estimates of carbon lost through peat extraction in Northern Ireland became of interest for UK calculations of carbon stocks and changes due to LULUCF. This loss was estimated for 1990-91 (Cruickshank, et al., 1996), but during the late 1990s and early 2000s it became apparent from people working in conservation and land management and from local studies (McCann, 1999) that cutting of peat for fuel had declined; notably, Forest Service lettings of banks for turf cutting fell from 1050 in 1990 to around 60 in 2007 (Forest Service, pers. comm.). A resurvey of peat extraction for fuel and revision of associated carbon loss was required. Additionally, data on extraction of peat for horticulture comparable with that for 1990-91 became less available. It was necessary to recalculate the amount of peat extracted for horticulture, and consequent carbon loss, for 1990-91 using a method that could be applied for 2007-08.

19.2 Methodology

Extent of Extraction

Extent of mechanized fuel peat extraction

In 1990-91, incidences of mechanized fuel peat extraction were located and their size estimated by field survey throughout Northern Ireland (Cruickshank et al., 1995). Records of location, by Irish grid reference, and of size were held in a 'peat extraction database'. For the re-survey, a sampling approach was adopted for fieldwork carried out in the cutting seasons of 2007 and 2008.

Peatland in Northern Ireland, excluding that under forest, had been captured by the 1km Irish grid squares and stored in a database (Cruickshank et al., 1993). A random sample of 5% of grid squares with peatland was generated for blanket and for lowland peat. Grid squares in county Down, and south and east county Armagh were excluded because any lowland peat remaining is fen peat and unsuitable for extraction for fuel. Blanket peat in this area is thin, on steep slopes and also unsuitable for mechanical extraction. No extraction was recorded in this region in 1990-91. The 5% random samples of peatland generated 151 grid squares with blanket peat and 85 grid squares with lowland peat. Interrogation of the peat extraction database showed that these sample squares had 5% of 1990-91 extraction incidences on blanket peat and 6% of those on lowland peat. Each sample grid square was visited in the summer cutting season of 2007 or 2008 and location and size of each incidence of mechanized extraction were recorded. Comparisons could be made for each sample grid square with the 1990-91 data stored in the extraction database.

Extent of hand cutting of peat for fuel

In 1990-91, incidences of hand extraction were located during the survey for mechanized cutting. Incidences were recorded in a database by grid reference. For the 2008 re-survey, the 5% sample of grid squares with peat yielded 2% of the active hand cutting sites recorded on blanket peat in 1990-91 and 3% of those recorded on lowland peat. With this low number of sites and the clustered distribution of hand cutting (Cruickshank et al., 1995), the sample grid squares were not considered an appropriate approach for the resurvey of hand cutting. Instead, two blocks were taken where hand cutting was relatively common in 1990-91 and machine cutting was rare; one in north county Londonderry and one in south county Antrim.

Extent of peat extraction for horticulture

The extent of peat extraction for horticulture in 1990-91 was based on (1) locations and volumes of peat to be extracted as stated in planning applications and consents given for each site (Cruickshank et al., 1996) and (2) additional, unlisted sites located by field survey. These were generally small sites, less than 5 ha, that appeared to have been in operation for many years. Subsequent to the 1990-91 survey, it proved difficult to obtain similar data from planning applications and consents as estimates of volume to be extracted were not given for all sites. Also, the forecast areas and volumes were not necessarily the actual productive areas and volumes. So that results would be as comparable as possible, the 1990-91 estimates of peat extraction had to be revised using a methodology that could be repeated for 2007-08.

The existing database of sites of peat extraction for horticulture (1990-91) gave the Irish grid reference and area for each site, and the type of extraction. In 1990-91, vacuum harvesting accounted for 57% of the area of extraction for horticulture. Sites of bare, loosened peat are clearly identified and located on satellite images and in 1990-91 their areas were measured manually on hard copies of the images. Field visits were made to confirm type of extraction and activity.

One extensive site of extraction for horticulture in 1990-91 was on blanket peat. The bare peat enabled the site to be easily identified and its size measured on satellite images, but extraction was not by vacuum but by a similar method to that used to extract fuel peat. The site was 22% of the area of extraction for horticulture.

Other 1990-91 sites of extraction for horticulture listed in planning applications and consents and not identified as vacuum extraction were field checked and classified as to type; all but one were sod cutting. All the unlisted sites, located by field survey, were also sod cutting. Sites of sod cutting are less distinct on satellite images than sites of vacuum extraction. Their extent was mapped onto satellite images after field visits and their area measured manually. Sod cutting was confined to sites southwest and northwest of Lough Neagh and was 18% of the area of extraction for horticulture.

The remaining site of extraction for horticulture listed in planning applications and consents, and located in county Fermanagh, was for mushroom casings. At that site peat was excavated from a face of peat and thereby had little areal extent. The excavated peat was put through a hopper to produce ‘turfs’ similar to those of fuel extraction.

For the re-survey in 2007-08, extraction sites listed in planning applications and consents were located on satellite images and their areas were measured using

ARCVIEW. Each site, including those from 1990-91, was visited to ascertain the type of extraction and whether it was active. Field survey was also carried out to look for possible new, unlisted sites not evident on satellite images.

Estimates of Carbon loss from peat extraction

Estimate of carbon loss from mechanized fuel peat extraction

The 1990-91 survey of machine extraction included discussions with people engaged in extraction of peat and in marketing the machinery, and also a review of experience in the Republic of Ireland. That work revealed a range of estimates of tonnes of peat extracted per hectare per year, depending on type of peatland, weather and commerciality of the operation. To accommodate that evidence, Cruickshank et al. (1996) made lower (60 t/ha/yr) and upper (100 t/ha/yr) estimates of the amount extracted.

During the 1990-91 field survey, samples of machine cut peat were collected for laboratory analysis and the mean % dry matter and mean % carbon (half the % loss on ignition) were derived. Carbon loss was estimated as area (ha) *x* tonnes (per ha) *x* % dry matter (67%) *x* % carbon (49%), with the calculation carried out for low and high rates of extraction (60 and 100 t/ha). As methods of extraction remained the same in 2007-08, components in the calculation of carbon loss were retained. The 2007-08 re-survey was by sampling, so the area of extraction for Northern Ireland was interpolated from the sample results.

Estimate of carbon loss from hand cutting of fuel peat

In 1990-91, Cruickshank et al. (1996) found that on average each incidence of hand cutting served two households. Each household would extract the same amount as from a plot of mechanized extraction, i.e. the amount needed to supply the house for the year. The % dry matter and % carbon of the extracted turf was the same as turf from mechanized extraction. All these components in the calculation of carbon loss from hand cutting were held constant in 2008.

Estimate of carbon loss from horticultural peat extraction

The volume of peat removed by vacuum harvesters in 1990-91 was re-estimated using the area of extraction recorded in the 1990-91 database and depth removed (as noted above volume had originally been taken from planning applications). For the 1990-91 re-estimates, an annual removal of 10 cm of peat by vacuum harvesters was adopted following discussion with producers, and a review of estimated extraction rates in the Republic of Ireland (Tomlinson, 2004). This conservative estimate of 10 cm relates to a long-term average that considers variations in seasonal conditions. As for fuel peat, the carbon content of horticultural peat was derived in 1990-91 following laboratory analysis of field samples for % dry matter and % carbon. In 2007-08, vacuum extraction procedures remained similar to 1990-91 so that volume of peat extracted was estimated in the same way as for the revised 1990-91 estimates. The carbon content for 1990-91 (5.08 kg/100 litres) was held constant for 2007-08.

In 1990-91 some horticultural peat was extracted as peat sods and at one site for mushroom casings. For sites of sod extraction, their areas were known but no estimates of annual amounts extracted were given in planning applications and consents, nor were estimates available locally for these and the non-listed sites. In the original 1990-91estimate, volume of peat extracted by sod extraction was assumed to be the same as by vacuum extraction. In revising the 1990-91 estimates, discussions with staff experienced in peat extraction in the Republic of Ireland produced an estimate for sod extraction of 200 t/ha/year with a moisture content of 35%. These values were used, with a carbon content of 49%, to calculate a figure for carbon loss from sod extraction of around 35 tC/ha (51 tC/ha was estimated in the original survey), which was applied to the area of sod extraction in 1990-91. Samples of sod peat were not available in 1990-91 for analysis so the carbon content of peat from these types of extraction was taken as that for fuel peat (49%) because of the similarities of the product and drying process.

By 2007-08, sod extraction sites were either out of production or had changed to vacuum extraction. The estimated volume of peat extraction for mushroom casings in 1990-91 and in 2007-08 remained as that in the planning application. For the blanket peat site, 1990-91 peat production (tonnes) was known from local sources and was converted to t/ha. The harvesting method was similar to that of fuel extraction so that dry matter was taken as 67% and %C as 49%. In 2008, peat production (t/ha), % dry matter and %C were kept the same as in 1990-91, but on the reduced area.

19.3 Results

Mechanical extraction for fuel

Expanding the results from the sample survey gave a total area of mechanical extraction for fuel in 2007-8 of 329 ha (± 140 ha with 68% probability), less than 10% of the area extracted in 1990-91 (3855 ha). At a low rate of extraction, the carbon loss estimated for 2008 was 6481 tC/yr (± 2758 tC/yr) and at a high rate of extraction was 10 807 tC/yr (± 4599 tC/yr). The corresponding estimates for 1990-91 were 75 936 tC/yr and 126 623 tC/yr (Table 19-1).

Table 19-1. Carbon loss due to peat extraction in Northern Ireland (tC/yr). [1] At 12% of 1990-91 incidences. [2] At 17% of 1990-91 incidences.

	Low rate of extraction		High rate of extraction	
	1990-91	**2008**	**1990-91**	**2008**
Horticulture	29 995	36 000	29 995	36 000
Machine fuel	75 936	6481	126 623	10 807
Hand fuel	2170	270[1] - 385[2]	3610	450[1] - 645[2]
Total	**108 101**	**42 751 – 42 866**	**160 228**	**47 257 – 47 452**

Hand cutting of fuel peat

The field resurvey revealed that incidences of hand cutting had declined from 1990-91 to 2008; in north Londonderry to approximately 12% of the number recorded in 1990-91 and in south Antrim to approximately 17% of their occurrence in 1990-91. At 12% of 1990-91 incidences, carbon loss in 2008 from hand cutting across Northern Ireland was estimated as 270 tC/yr at low rates of extraction and 450 tC/yr at high rates. At 17% of 1990-91 incidences the corresponding estimates were 385 tC/yr and 645 tC/yr. These estimates compare with the 1990-91 estimates of 2170 tC/yr and 3610 tC/yr (Table 19-1).

Extraction for horticulture

The total area of peat extraction for horticulture increased from 576 ha in 1990-91 to 689 ha in 2007-08. Although sod extraction sites ceased production or had been converted to vacuum harvesting, and the blanket peat site had declined from 178 ha to 39 ha, some vacuum harvesting sites had expanded and new sites had opened. The carbon loss increased from around 30 000 tC/yr in 1990-91, to around 36 000 tC/yr in 2007-08 (Table 19-1). In 2007-08, vacuum harvesting accounted for 95% of carbon loss through extraction for horticulture compared with 75% in 1990-91.

Total carbon loss

The estimates of carbon loss from peat extraction in 2008 range from 42 751 tC/yr to 47 452 tC/yr at low and high rates of peat extraction, or approximately 40% and 30% respectively of estimated losses in 1990-91 (Table 19-11). Whereas in 1990-91, peat extraction for fuel (hand and mechanical) accounted for 76-81% of carbon loss from peat extraction, in 2008 it accounted for 16-24%

19.4 Discussion

There has been an overall decline in annual carbon loss resulting from peat extraction during the period 1990-91 to 2007-8, caused mainly by a marked fall in extraction for fuel. The estimated error in area of machine fuel extraction resulting from the sampling strategy used for the 2007- 8 resurvey was quite large (329 ha ± 140 ha with 68% probability). Forest Service turbary lettings in 2007 were 6% of the number in 1990; the estimated area of machine extraction from the resurvey was 8.5% of the area in 1990. Forest Service lettings do not distinguish between hand and machine cutting and do not give area, but the figures may suggest that the area of machine cutting in 2007-8 has not been greatly over- or under- estimated.

The results show an increased carbon loss resulting from extraction of peat for horticulture between 1990-91 and 2007-08 of around 6000 tC/yr. However, carbon losses calculated are for a particular year and a number of factors could affect that estimated loss. First, although the extraction rates applied had some recognition of seasonal variability, extraction is weather dependent so that, for example, some smaller sites that appeared abandoned in the wet summers of 2007 and 2008, and are classed as such in the survey, may be only temporarily so. Second, revisits to areas with smaller extraction sites, as around the southwest shores of Lough Neagh, also indicate that the number of sites and their extent are more varied year on year than sites of larger companies. Third, the lower estimate of C loss from sod extraction (35 tC/ha) used in the revised 1990-91 estimates compared with the original study (51 tC/ha) has increased the estimated loss by around 2000 tC/yr; if the original estimate were to be used, the increased C loss due to extraction for horticulture would be 4000 tC/yr rather than 6000 tC/yr. Finally, since the first survey in 1990-91 the quality and availability of satellite and digital aerial images, and of image processing software, has improved. Measurement of sites was more accurate in 2007-08.

The estimates of carbon loss are based on that in the peat removed from bogs, carbon released as carbon dioxide or methane in the processes of extraction (Wilson & Farrell, 2007) or carbon lost in runoff (Worrall et al., 2003) from extraction sites are not considered. These carbon losses require long-term research that encompasses all stages from initial site preparation (including drainage), through extraction to after-use, and for both fuel and horticulture extraction sites.

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20. Quantification of uncertainties in the inventory (WP3)

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20.1 Introduction

This report describes the work that has been carried out in WP3 towards its final milestone, due 31/5/2009, of providing "Uncertainty analysis and recommendations for changes in the future". In the first phase of the project, the work in WP3 had focused on reviewing existing guidelines for uncertainty assessment in the environmental sciences, including the IPCC Good Practice Guidance reports (see the 2007 Annual Report). We also formulated a methodology for use in WP3 and identified sources of information on uncertainty for data and model parameters. In the second year we concentrated on further development and testing of our methods, including preliminary application to some of the calculations for the UK Inventory (2008 Annual Report). The work in the past twelve months, reported in this chapter, improved and extended that analysis. In our description of the work, we focus on uncertainty assessment for the main component of LULUCF, i.e. forest afforestation plus productivity (5A, 5G). Uncertainty quantification for the other land-use changes was carried out in WP2.13 with technical support from WP3, and is reported in a separate chapter.

The calculation of changes in carbon stocks due to afforestation (5A) and harvested wood products (HWP, 5G) is carried out by means of the carbon accounting model CFLOW. The use of the CFLOW model makes our calculation of stock changes caused by afforestation a Tier 3 approach. A detailed description of the CFLOW calculations was given in previous year's annual report. The calculations depend on input data of various kinds. Uncertainties in these data are propagated to the Inventory, and there are additional uncertainties associated with the structure of the carbon accounting model, and its parameters. This chapter discusses all three sources of uncertainty: input data (see §2), model structure (§3) and model parameters (§4). This is followed by a review of information from various international collaborations relevant to uncertainty assessment of greenhouse gas inventories (§5). The remainder of the chapter consists of discussion and conclusions (§6), recommendations for future work (§7) and output from the work in terms of knowledge transfer between colleagues and publications (§8).

20.2 Uncertainty with respect to input data

The input data required by CFLOW are afforestation rate (ha y^{-1}) and yield class (mean wood volume production in m^3 ha^{-1} y^{-1}), both for a range of different forest types and regions in the U.K. The sensitivity of CFLOW to these input data was already analysed in the previous Annual report. So far unexplored was the interaction between the uncertainties in 5A and 5G. Figure 1 shows time series of carbon stock change per unit land area from the year of tree planting, both for the two categories individually and for the combined flux. The differently coloured time series in each panel represent variation in input values for yield class, ranging from 8 to 16 m^3 ha^{-1} y^{-1}. All values are given as the difference with yield class 12, which is the default in the Inventory. Uncertainty about the yield class – and the associated rotation length -

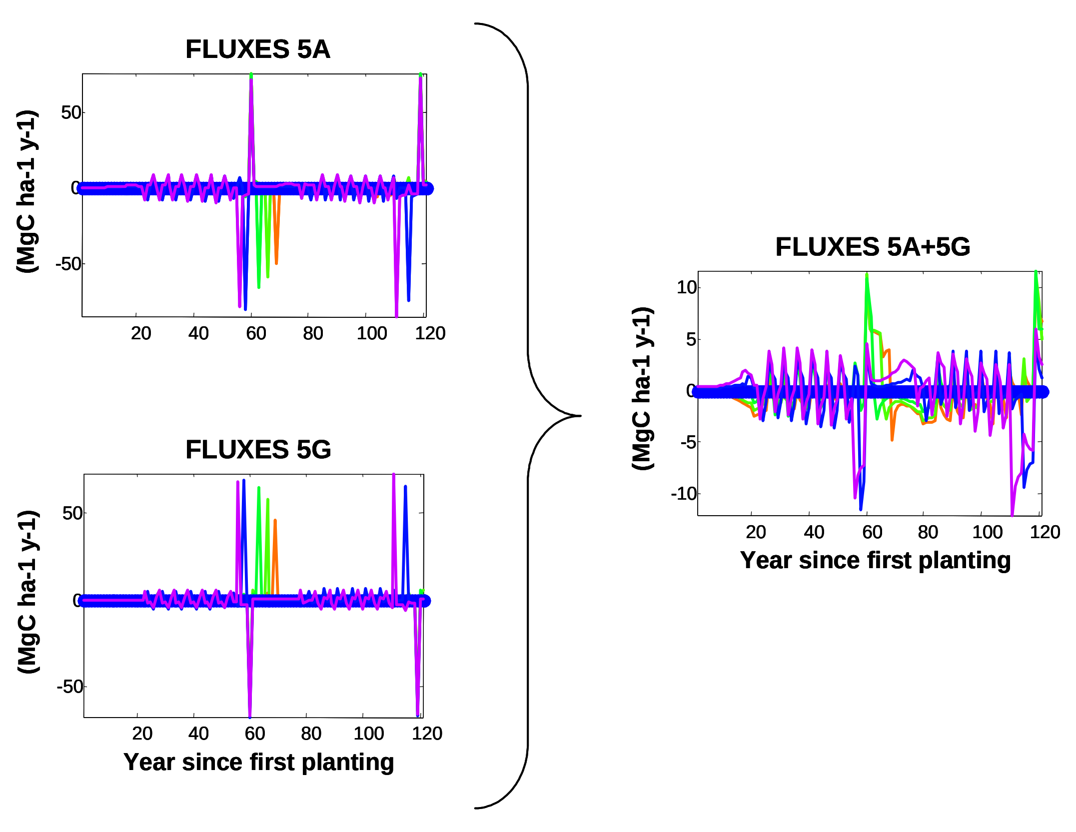


Figure 20-1. Changes in stocks of carbon, per unit land-area, from the year of tree planting. Top-left: carbon in trees and soil (5A); Bottom-left: carbon in harvested wood products (5G); Right: sum of 5A+5G. Colours represent different yield classes. All fluxes are expressed relative to yield class 12.

means that, in a given year area-specific fluxes in 5A can have an uncertainty exceeding 50 MgC ha^{-1} y^{-1}, and similarly for 5G. However, the uncertainty of the combined categories, 5A+5G, is up to 5 times less than that for the individual categories, because of the obvious opposite effect that forest felling has on the two types of carbon stock. It is therefore important to always consider the uncertainties in these two components of the Inventory simultaneously. For other details of this analysis of sensitivity to yield class, see the previous report.

20.3 Uncertainty with respect to model structure

Information about carbon dynamics in forest stocks other than tree biomass is still quite scarce. The CLIMSOIL report on the response of European soils to environmental change identified the U.K.'s National Soil Inventory and the Countryside Survey as two of the few sources of information on soil carbon change that were based on extensive resampling of field plots (Schils et al. 2008, see also §5). Unfortunately these two data sets may even be insufficient for the U.K. itself as the first suggests widespread carbon loss and the second does not. Data availability is limited in particular for changes in soil carbon and undergrowth in the years immediately following planting. The work of Hargreaves et al. (2003, "Carbon balance of afforested peatland in Scotland", Forestry 76: 299-317) is a rare source of data and inspired the approach taken in CFLOW. In CFLOW, following afforestation essentially three different independent processes are started. The first is the uptake of carbon by new tree biomass followed by its flow to and decomposition in the soil. The second is the gradual loss of pre-existing soil carbon formed before planting. The third is a temporary process of carbon removal by undergrowth such as grasses when the trees are still small. The first of these processes is the largest in magnitude and is mainly responsible for any carbon sink associated with tree planting. However, the second and third processes do affect the Inventory considerably (Figure 20-2).

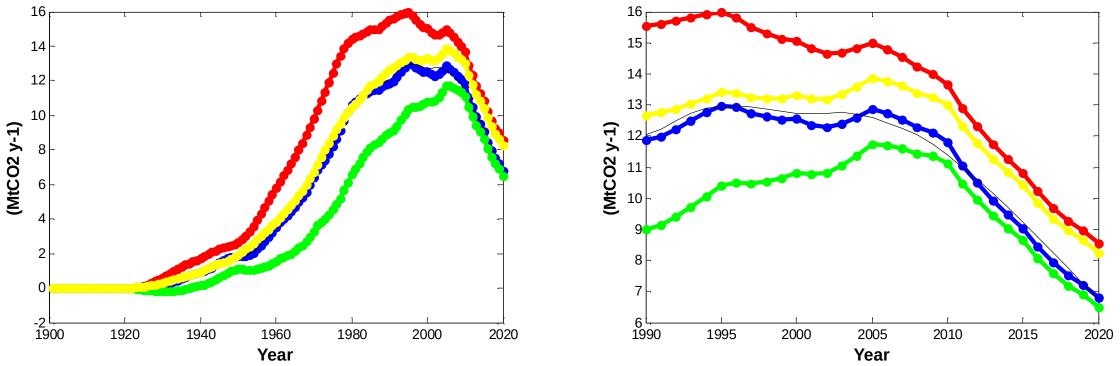


Figure 20-2. Total carbon stock change due to U.K. afforestation (5A+5G). Left: 1900-2020, right: 1990-2020. Blue line: actual inventory method. Red: no emissions from pre-existing soil carbon. Green: no removal by grass growth. Yellow: neither process (i.e. "Red+Green").

According to the CFLOW calculations, the peak of afforestation-related annual increase in carbon stock (5A+5G) is reached in the period 1980-2000, after which a decline is foreseen due to the decrease in afforestation at the end of the 20th century (Figure 20-2, left). The assumptions regarding the dynamics of pre-existing soil carbon and undergrowth do not change that general pattern. In contrast, the difference with the reference year 1990 can be pronounced, depending on whether the processes are included in the model or not (Figure 20-2, right). Because the implementation of both processes was based on a limited amount of empirical information, the reliability of the current model version is to some extent uncertain, and it is important to acquire more data. Note that the variation between the lines in Figure 20-2 overestimates our uncertainty regarding these processes, because the existence of the processes is not in doubt – their magnitude and change over time are. Figure 20-3 shows a comparison between methods for the dynamics of pre-existing ("old") soil carbon. The Inventory

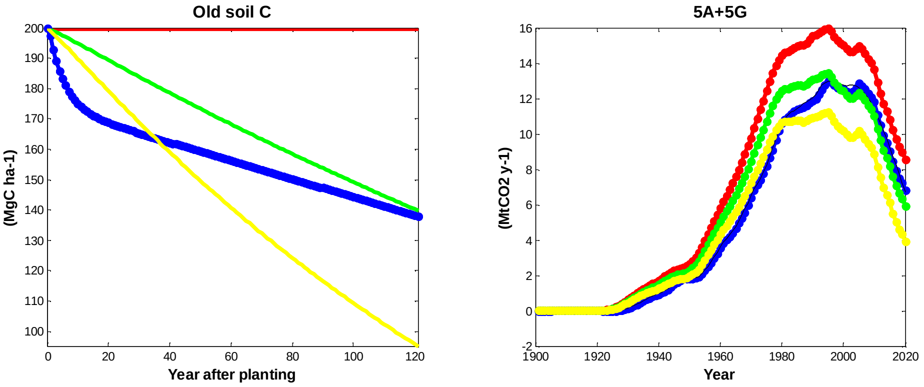
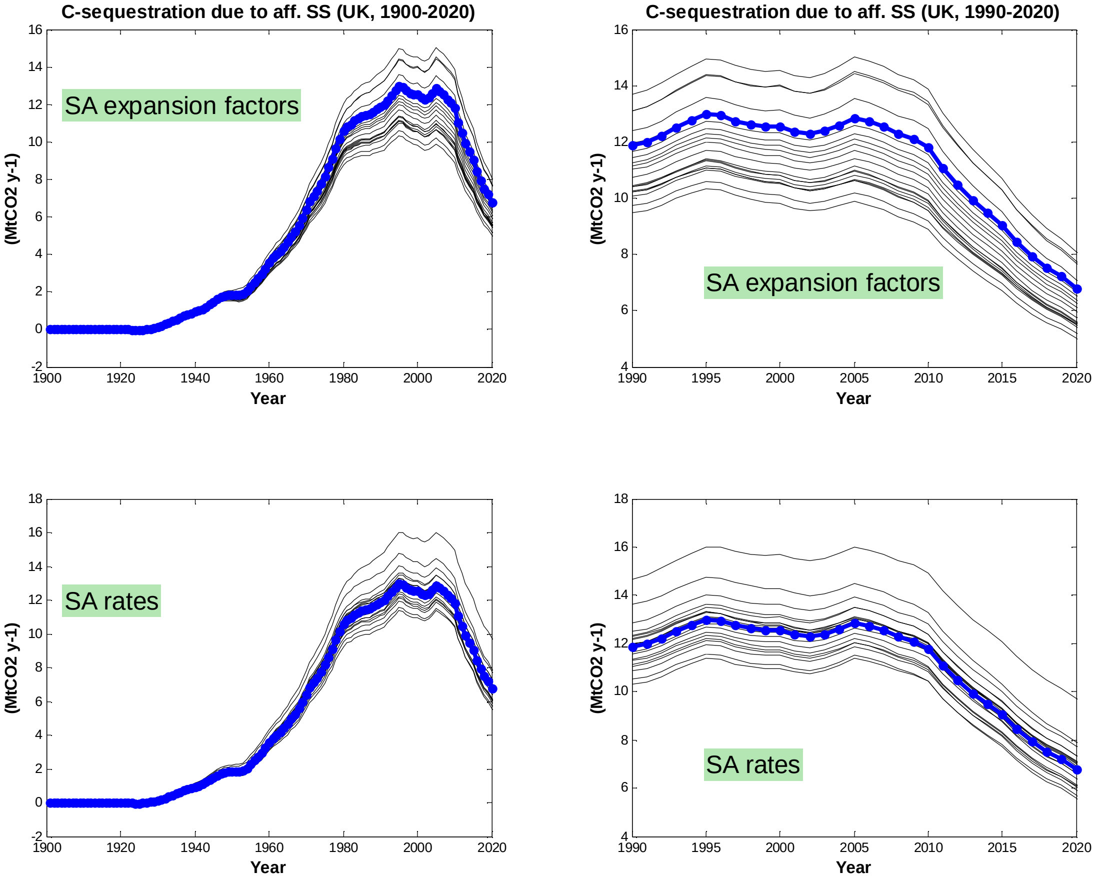


Figure 20-3. The impact of different assumptions about pre-existing ("old") soil C on calculations. Left: area-specific changes in old C, right: total carbon stock change due to U.K. afforestation (5A+5G). Blue line: actual inventory method with zero-order change in old C. Other curves: first-order change with 0.5% decrease in old C per year (yellow), 0.25% (green), 0% (red).

uses a zero-order method where the annual change in old C does not depend on its pool size but only on time elapsed since planting. In Figure 20-3, we compare that model approach with a first-order approach where a certain fraction of old C is decomposed every year. Calculations are done with three possible values for the decomposition rate constant: 0, 0.25 and 0.5 % y^{-1}. The results show that these alternative models again do not affect the overall pattern for the whole of the U.K. very strongly, so clearly that pattern is mainly driven by the history of changes in afforestation rate. However, the magnitude of the sink is affected as well as its interannual variability.

20.4 Uncertainty with respect to parameters

CFLOW calculates the flow of carbon through the forest ecosystem from the time of planting. As described before, afforestation rate and yield class are inputs to the calculations. The subsequent partitioning of carbon between different parts of the trees, litter and soil and the turnover of these pools is governed by the equations of CFLOW and the values of the parameters that govern the carbon partitioning and turnover. The carbon partitioning parameters in CFLOW are referred to as "expansion" factors because they include the key upscaling step from the wood volume input to whole tree carbon. The sensitivity of the model calculations to 30% uncertainty about these parameters, under a uniform distribution, is shown in Figure 20-4.



Figire 20-4. Sensitivity analysis (SA) of 5A+5G to changes in parameters. Top row: changes in expansion factors. Bottom row: changes in turnover rates. Blue lines: default parameterisation. Black lines: sample of 20 parameter vectors from a multivariate uniform distribution where every individual parameter has a range from 0.7 to 1.3 times its default.

Even more than in the analyses of the previous sections, we see that changes in expansion factors and turnover rates do not affect the overall time pattern of carbon sequestration due to afforestation. There are clear effects on the magnitude of the sink but only minor differences between sink strength in any given year and, for example, the reference year 1990.

20.5 International collaborations and their implications for WP3

In the previous Annual report, we presented five international collaborations, relevant to the work in WP3. Details, including web-links, of these collaborations are given below in §8.1. In this paragraph we summarise the progress made in these activities. First, the NitroEurope project has entered its fourth year. The project aims to quantify nitrogenous greenhouse gas emissions from European ecosystems. It has become clear that the Bayesian approach to quantifying and reducing uncertainties is easy to implement and can be very powerful provided sufficient calibration data are available (Van Oijen 2008). The same appears true in this project – see the chapter on WP2.13 which deals with uncertainties in time-series of land-use change matrices. Unfortunately, some of the other collaborations identified general problems with data availability. A key conclusion from the CLIMSOIL literature review has been that the very few studies that have tried to quantify changes in soil carbon stocks across larger regions do not produce a consistent result (Schils et al. 2008). The CLIMSOIL review does point out that the U.K. has some of the better data, from the two resampling studies carried out by the Countryside Survey and the National Soil Inventory, but only the NSI finds widespread carbon loss. This hampers the use of such data in Bayesian calibration of the modelling carried out for the Inventory. Earlier Annual reports of WP3 already flagged the lack of good soil data. The two COST Actions 603 and 639 have made progress in tabulating the many different data sets, models and methods of uncertainty analysis that are used throughout Europe, but neither activity has yet reached any conclusions – apart from reiterating the poor quality and quantity of soil data and the uncertainty about proper model structure - or provided any recommendations. With respect to the LULUCF Inventory, the final activity listed in §8.1 is perhaps the most relevant one, i.e. the preparation of a new EU-funded COST action fully devoted to the issue of uncertainty in national GHG Inventories – but obviously that work is still to start, although the papers from the preparatory meeting in 2007 are now underway (e.g. van Oijen & Thomson, subm.). The group proposing the new COST Action recognises that no country has yet been able to produce a detailed and comprehensive uncertainty assessment of their GHG Inventory for any Tier 3 approach – one of the key objectives of the work will be to produce a recommended method.

20.6 Discussion and conclusions

The uncertainty quantification carried out for 5A+5G must be seen as preliminary, for two main reasons. First, the uncertainty of the calculated forest sink associated with assumptions about forest management was not assessed, due to lack of information about current forest management in the UK. Also, a lack of internally consistent information about the spatial heterogeneity of UK soils, and the response of their carbon pools to environmental change, precluded a complete assessment of the quality of the calculations carried out to produce the inventory. However, the uncertainty analysis did reveal the following:

- The uncertainty for the total carbon flux from 5A and 5G combined is much less than the sum of the two uncertainties viewed separately. This is because the opposite effect that harvesting has on both fluxes creates a negative correlation between the two. It is therefore not useful to only report uncertainties at the component level.
- The carbon sink associated with afforestation is highly sensitive to the presence and parameterisation of the following two processes in the most recent version of CFLOW: (1) emission of C from decomposing organic matter that was already present in the soil at the time of afforestation, (2) the removal of carbon by grasses and shrubs in the period after planting before the forest canopy closes. Because uncertainty about these processes propagates

strongly to the output, they need to be quantified more widely to establish whether they are spatially variable.

- Furthermore, replacing the zero-order method (only dependent on time elapsed since planting) by which CFLOW calculates emission from pre-existing carbon by first-order methods (dependent on current pool sizes) changes the time-pattern of emissions significantly.
- The sensitivity of calculated carbon fluxes to CFLOW parameters (both expansion factors and decomposition rates) is very large, but this is mainly for the flux sizes themselves and less so for how the fluxes change between years. The sensitivity to parameterisation thus has only a minor effect on the difference between fluxes in any given year and a reference year.

CFLOW is fundamentally a simple box-flow model. Such models are often used for estimating C-sequestration rates. Other examples are CO2FIX, CARBWARE, and the models used in the inventories of Finland and Canada (see Proc. 2nd Int. Workshop on Uncertainty in Greenhouse Gas Inventories, IIASA, 2007 http://www.ibspan.waw.pl/ghg2007/GHG-total.pdf). They tend to behave linearly with respect to their input and parameter uncertainties. If the model is fully linear then for each box the equilibrium C-stock is inflow rate times residence time, so any change in residence time has a proportional effect. However, the CFLOW calculations are not fully linear because no equilibrium is assumed and some of the carbon allocation parameters vary with inputs (forest yield class). This implies that uncertainty associated with CFLOW can not be assessed analytically and has to be ascertained using Monte Carlo sampling, as was done in the work reported here.

20.7 Outlook

The uncertainty assessment has identified processes (the dynamics of pre-existing carbon and the role of undergrowth) whose magnitude needs to be examined more thoroughly. Some uncertainties mainly affect the overall level of GHG fluxes, but have little impact on interannual variability (e.g. differences between any given year and the reference year 1990) whereas others have the opposite effect. To make the uncertainty quantification more comprehensive in the coming years, it will be important to include more information about spatial variability of soils and vegetations. Otherwise the CFLOW model seems to be quite robust with respect to its input values and parameterisation, with the caveat that the consequences of changes in forest management have not been accounted for. Finally, the strong impact of the structural changes of CFLOW with respect to soil carbon dynamics suggests that a thorough comparison with other models would be worthwhile.

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21. Participation in the UK national system and collaboration with other research activities (WP 4)

21.1 Participation in the UK national system

CEH has participated in the UK national system meetings as technical experts for LULUCF. We work closely with AEA, the contractor responsible for the total UK inventory.

21.2 Collaboration with other research activities

CEH, and other project partners, have taken part in a number of research collaborations relevant to the inventory during the 2008/09 project year.

21.2.1 National collaborations

LULUCF Emissions and Removals mapping (sub-contract with AEA)

This sub-contract with the contractor responsible for the total UK inventory entails the development of methods to map LULUCF activities from the inventory at the local authority scale.

QUEST

One of the main themes of QUEST, a NERC-funded UK research programme, is the contemporary carbon cycle and its interactions with climate and atmospheric chemistry. Several groups participating in the UK GHG Inventory project also apply common modelling approaches within QUEST (CEH, University of Aberdeen & University of Sheffield).

Climate change mitigation options in Scotland (with AEAT)

Identification and modelling of potential policy options in the LULUCF sector which would help the Scottish Government to achieve their proposed 80% emissions reduction target in 2050.

21.2.2 International collaborations

Besides the abovementioned projects within the UK and constituent countries, there are a number of international collaborations that are relevant to the development of the UK GHG Inventory.

NitroEurope IP

This is an EU-funded integrated project led by CEH that aims to quantify the non-CO_2 GHG balance across Europe. CEH and the University of Aberdeen participate in NitroEurope. The project supplies information on GHG emissions as well as calculation methods that are useful for WP's 2 and 3 of the Inventory project.

CarboEurope IP

CarboEurope also is an EU-funded integrated project, with UK participation by the CTCD group, CEH and the University of Aberdeen. The work in CarboEurope supports the Inventory activities in WP 2.14.

COST 639

This is an EU-funded project on “Greenhouse gas budget of soils under changing climate and land use”, and has UK involvement from CEH, University of Aberdeen, Forest Research and NSRI. One of the aims of COST 639 is providing recommendations on the improvement of national GHG inventories in particular the contribution from soils.

22. Promotion of scientific knowledge of LULUCF issues and provision of technical advice (WP 5)

This work package covers the provision of advice to the UK Government and Devolved Administrations on matters relating to the UK inventory and LULUCF activities and the development and promotion of scientific knowledge of LULUCF issues through meeting attendance and publications. Activities relevant to this work package that took place between June 2008 and May 2009 are listed below.

22.1 Meetings/presentations

RothC-Biota – a carbon accounting tool. Presentation at Eurosoil meeting, Vienna, August, 2008 (B. Foereid).

UN-ECE Workshop, Harvested Wood Products (HWP) in the context of climate change policies, Geneva, Switzerland, September 2008 (R. Matthews).

Technical workshop on LULUCF reporting issues under the Kyoto Protocol. JRC Ispra, November 2008 (K. Dyson)

National Inventory Steering Committee Meeting to present LULUCF Sector data November 2008 (Ronnie Milne & Kirstie Dyson)

Integrating and Modelling Scientific Understanding to Inform Decisions about Forest Sector Carbon Management in Great Britain. The European Forest-Based Sector: Bio-Responses to Address New Climate and Energy Challenges, organised by the French Ministry of Agriculture and Fisheries with support from the European Commission, Nancy, France, November 2008 (R. Matthews).

PGL Dalguise, Craigvinean near Dunkeld, Climate Change and Trees (Forest Management Issues and Carbon Accounting). November 2008, (R. Matthews).

Wyre Forest Pioneer Centre, The Power of Wood, (How to balance or cook the forest carbon books) November 2008 (R. Matthews).

FC England Conference. Woodland Carbon Offset Schemes: The Scientific Basis. Tackling Climate Change – The Roles of Trees, Woodlands and Forestry, Newcastle, November 2008 (R. Matthews),

NitroEurope General Assembly, Gothenburg, January 2009 (M. van Oijen).

FC Scotland Conference Carbon life cycle of wood. Sustainable Timber Construction, Edinburgh, February 2009 (R. Matthews).

Invited seminar National University of Ireland, Galway. Paper to International Peat Society Annual Assembly March 2009 (R. Thomlinson).

Visit from Russian Statistics Committee. Presentation on LULUCF - how the UK does it. March 2009 (K. Dyson)

Annual Meeting and the Stakeholders meeting of ICOS in May 2009. (J. Grace)

Brussels, COST 603 Meeting on Modelling for Sustainable Forestry, May 2009 (M. van Oijen).

22.2 Requests for information/advice

CEH responded to a large number of requests for advice/information from Defra, Universities, other institutes and members of the public during this project year. We responded promptly to these requests and coordinated responses from a broader range of CEH staff or project partners as required.
DEFRA/English Heritage: contributions to peatland classification map for Northern Ireland, UK Peatland Partnership Project.

DECC: Information provided for the EU submission of the BAR and the band

DECC: Advice on CO2 emission from arable land converted to forestry or grassland.

DECC: Advice on CO2 emissions from National Parks

DECC: Advice on weather the decrease in woodland creation has been reflected in the inventory.

DECC: Advice on recent suggestions from NE that the GHG inventory underestimates the losses of carbon from peat.

Local Authority - West Dorest: Explanation of data included in LULUCF Sector of GHG Inventory

Independent consultant: Advice on removals of carbon by afforestation in Scotland

Independent consultant: Advice on carbon benefits of tree planting to Local Authorities.

Independent consultant: Advice on which type of land use will have the highest carbon storage potential.

Independent consultant: Question on CO2 absorption rates of an average hedge in the UK in comparison to an average tree.

Scottish Government (Rosie Telford): Advice on removals of carbon by afforestation in Scotland

Scottish Government: Advice on methods used to prepare LULUCF Sector of GHG Inventory

Scottish Government: Climate Change and Land Use at the request of the Scottish Government and the sustainable Development Commission for Scotland.

Scottish Government: gave evidence to the Scottish Parliamentary Select Committee for Transport, Infrastructure and Climate Change on climate change, land use and inventory needs.

SHE/SNIFFER: Contributions to the Northern Ireland input to the report “Climate change, land management and erosion in the organic and organo-mineral soils of Scotland and Northern Ireland” due to be published in early July 2009.

University of Aberdeen: Summer School for Uncertainty in Modelling.

University of Edinburgh: MSc Course lecture on methods used in LULUCF Sector of UK GHG Inventory to Climate Change Management

University of Glasgow: Course Environmental Statistics

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23. Provision of an archive of the LULUCF inventory and projections (WP 6)

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CEH maintains a publicly accessible electronic archive of data and calculations relating to the LULUCF sector of the UK Greenhouse Gas Inventory on the website http://www.edinburgh.ceh.ac.uk/ukcarbon/. This archive has been updated with the latest inventory estimates for 1990-2007.

CEH has a wiki-based inventory manual for internal use, which is updated with new data and methods (see chapter 5, WP 2.1).

24. Appendices

24.1 Appendix 1: Summary Tables for 1990 to 2020 in LULUCF GPG Format (with High and Low future scenarios)

Table A1. 1: United Kingdom data for 2006 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) UK Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**2929**	**-12155**	**15822**	**-6130**	**7074**	**-1682**
1991	2841	-12636	15978	-6075	6989	-1416
1992	2285	-13320	15983	-6178	6907	-1109
1993	1124	-13679	15566	-6609	6848	-1003
1994	917	-14164	15618	-6548	6803	-793
1995	**1242**	**-13728**	**15750**	**-6461**	**6722**	**-1041**
1996	1000	-13605	15788	-6705	6707	-1185
1997	693	-13360	15530	-6822	6710	-1365
1998	77	-13322	15418	-7220	6669	-1468
1999	-202	-13489	15321	-7124	6605	-1513
2000	**-339**	**-13756**	**15339**	**-7221**	**6567**	**-1268**
2001	-460	-14280	15287	-7176	6543	-834
2002	-978	-14986	15313	-7512	6475	-267
2003	-1030	-15595	15384	-7321	6460	42
2004	-1771	-16238	15316	-7640	6423	368
2005	**-1934**	**-15721**	**15233**	**-7689**	**6384**	**-140**
2006	-1816	-15091	15279	-7790	6329	-544
2007	-1815	-14173	15288	-7967	6330	-1293
2008	-1876	-13620	15304	-8139	6302	-1724
2009	-1797	-12817	15294	-8182	6295	-2387
2010	**-1229**	**-10636**	**15276**	**-8306**	**6270**	**-3833**
2011	-892	-10586	15277	-8470	6267	-3380
2012	-392	-9770	15258	-8513	6246	-3613
2013	56	-8700	15240	-8608	6245	-4122
2014	347	-8322	15231	-8707	6234	-4089
2015	**912**	**-7617**	**15254**	**-8757**	**6224**	**-4193**
2016	1256	-7502	15239	-8847	6206	-3839
2017	1515	-7483	15226	-9013	6207	-3423
2018	1774	-7434	15218	-9077	6196	-3128
2019	2105	-6430	15209	-9167	6187	-3694
2020	**2724**	**-4744**	**15223**	**-9239**	**6177**	**-4693**

B (Low) UK Gg CO$_2$/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	*-1815*	*-14173*	*15288*	*-7967*	*6330*	*-1293*
2008	*-2904*	*-13586*	*14687*	*-8397*	*6112*	*-1720*
2009	*-3035*	*-12640*	*14475*	*-8541*	*6047*	*-2375*
2010	***-2556***	***-10415***	***14390***	***-8724***	***6001***	***-3809***
2011	*-2496*	*-10416*	*14265*	*-8965*	*5964*	*-3344*
2012	*-2438*	*-9769*	*14085*	*-9093*	*5902*	*-3563*
2013	*-2534*	*-8928*	*13880*	*-9282*	*5855*	*-4059*
2014	*-2824*	*-8809*	*13682*	*-9478*	*5793*	*-4013*
2015	***-2827***	***-8335***	***13505***	***-9623***	***5731***	***-4104***
2016	*-3011*	*-8447*	*13314*	*-9805*	*5665*	*-3738*
2017	*-3313*	*-8683*	*13125*	*-10087*	*5641*	*-3309*
2018	*-3574*	*-8873*	*12955*	*-10236*	*5591*	*-3012*
2019	*-3747*	*-8082*	*12779*	*-10413*	*5541*	*-3572*
2020	***-3554***	***-6554***	***12641***	***-10575***	***5502***	***-4568***

C (High) UK Gg CO$_2$/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	*-1815*	*-14173*	*15288*	*-7967*	*6330*	*-1293*
2008	*-828*	*-13629*	*15920*	*-7884*	*6493*	*-1728*
2009	*-464*	*-12896*	*16112*	*-7822*	*6543*	*-2402*
2010	***252***	***-10733***	***16185***	***-7880***	***6542***	***-3862***
2011	*839*	*-10648*	*16295*	*-7960*	*6576*	*-3425*
2012	*1672*	*-9745*	*16407*	*-7922*	*6603*	*-3671*
2013	*2513*	*-8552*	*16540*	*-7929*	*6647*	*-4193*
2014	*3250*	*-8037*	*16704*	*-7939*	*6694*	*-4173*
2015	***4248***	***-7193***	***16888***	***-7896***	***6739***	***-4289***
2016	*5014*	*-6947*	*17026*	*-7894*	*6776*	*-3947*
2017	*5703*	*-6804*	*17180*	*-7958*	*6828*	*-3543*
2018	*6364*	*-6639*	*17322*	*-7928*	*6868*	*-3260*
2019	*7082*	*-5523*	*17450*	*-7922*	*6914*	*-3837*
2020	***8097***	***-3731***	***17620***	***-7896***	***6952***	***-4847***

Table A1. 2: England data for 2006 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) England Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**5725**	**-2716**	**7496**	**-2549**	**4017**	**-524**
1991	5853	-2741	7581	-2502	3948	-433
1992	5479	-2847	7545	-2759	3881	-342
1993	5023	-2836	7168	-2814	3831	-327
1994	5020	-2877	7173	-2775	3792	-292
1995	**5200**	**-2722**	**7241**	**-2725**	**3727**	**-321**
1996	4960	-2846	7236	-2860	3709	-279
1997	4639	-2809	6992	-2917	3705	-333
1998	4229	-2781	6869	-3128	3670	-401
1999	4030	-2869	6757	-3048	3618	-428
2000	**3972**	**-2739**	**6742**	**-3058**	**3585**	**-559**
2001	3918	-2923	6658	-2952	3564	-429
2002	3634	-3151	6662	-3190	3510	-197
2003	3655	-3313	6695	-3141	3494	-79
2004	3350	-3520	6615	-3280	3463	72
2005	**3162**	**-3447**	**6507**	**-3307**	**3431**	**-21**
2006	3137	-3253	6522	-3396	3387	-123
2007	3124	-2905	6521	-3461	3384	-417
2008	3053	-2670	6512	-3562	3360	-587
2009	3032	-2438	6482	-3579	3351	-785
2010	**3038**	**-2189**	**6447**	**-3655**	**3330**	**-895**
2011	3025	-2305	6430	-3734	3324	-692
2012	3083	-2076	6398	-3758	3306	-787
2013	3206	-1339	6368	-3806	3302	-1319
2014	3229	-1276	6344	-3857	3292	-1274
2015	**3350**	**-1081**	**6348**	**-3894**	**3282**	**-1304**
2016	3384	-1042	6321	-3944	3265	-1217
2017	3377	-1088	6297	-4040	3264	-1056
2018	3426	-1120	6277	-4059	3253	-925
2019	3408	-1058	6257	-4111	3245	-924
2020	**3540**	**-495**	**6256**	**-4127**	**3235**	**-1328**

B (Low) England Gg CO$_2$/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	3124	-2905	6521	-3461	3384	-417
2008	*2547*	*-2677*	*6247*	*-3698*	*3260*	*-584*
2009	*2361*	*-2437*	*6121*	*-3767*	*3220*	*-776*
2010	***2277***	***-2200***	***6040***	***-3872***	***3187***	***-878***
2011	*2106*	*-2347*	*5945*	*-3990*	*3163*	*-665*
2012	*1955*	*-2180*	*5823*	*-4059*	*3122*	*-751*
2013	*1837*	*-1516*	*5690*	*-4157*	*3094*	*-1274*
2014	*1613*	*-1532*	*5566*	*-4257*	*3055*	*-1219*
2015	***1494***	***-1403***	***5466***	***-4345***	***3016***	***-1241***
2016	*1311*	*-1427*	*5349*	*-4443*	*2976*	*-1144*
2017	*1074*	*-1550*	*5238*	*-4605*	*2966*	*-975*
2018	*912*	*-1655*	*5139*	*-4669*	*2938*	*-842*
2019	*683*	*-1652*	*5032*	*-4769*	*2909*	*-836*
2020	***633***	***-1127***	***4948***	***-4836***	***2887***	***-1239***

C (High) England Gg CO$_2$/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	3124	-2905	6521	-3461	3384	-417
2008	*3560*	*-2663*	*6778*	*-3428*	*3462*	*-590*
2009	*3710*	*-2434*	*6845*	*-3390*	*3484*	*-795*
2010	***3811***	***-2177***	***6860***	***-3432***	***3476***	***-916***
2011	*3926*	*-2273*	*6898*	*-3468*	*3491*	*-724*
2012	*4130*	*-2012*	*6924*	*-3453*	*3500*	*-829*
2013	*4420*	*-1236*	*6961*	*-3456*	*3521*	*-1370*
2014	*4624*	*-1132*	*7009*	*-3461*	*3542*	*-1334*
2015	***4924***	***-896***	***7084***	***-3450***	***3560***	***-1374***
2016	*5133*	*-818*	*7126*	*-3453*	*3573*	*-1295*
2017	*5310*	*-828*	*7180*	*-3498*	*3599*	*-1142*
2018	*5523*	*-827*	*7222*	*-3468*	*3616*	*-1020*
2019	*5662*	*-733*	*7259*	*-3473*	*3636*	*-1027*
2020	***5960***	***-140***	***7325***	***-3438***	***3652***	***-1439***

Table A1. 3: Scotland data for 2006 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) Scotland Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**-2528**	**-7535**	**6102**	**-2104**	**1774**	**-765**
1991	-2784	-7925	6175	-2115	1762	-682
1992	-3171	-8358	6222	-2196	1750	-589
1993	-3524	-8702	6197	-2231	1743	-531
1994	-3714	-9052	6248	-2207	1739	-442
1995	**-3624**	**-8885**	**6313**	**-2180**	**1726**	**-598**
1996	-3630	-8818	6359	-2255	1728	-644
1997	-3661	-8781	6354	-2315	1733	-652
1998	-3822	-8845	6372	-2435	1729	-644
1999	-3920	-9070	6391	-2389	1719	-571
2000	**-3912**	**-8850**	**6427**	**-2433**	**1714**	**-771**
2001	-3978	-9141	6462	-2493	1713	-519
2002	-4157	-9593	6486	-2558	1701	-192
2003	-4202	-10034	6524	-2420	1701	26
2004	-4607	-10452	6539	-2580	1696	191
2005	**-4586**	**-10132**	**6569**	**-2591**	**1691**	**-122**
2006	-4463	-9742	6600	-2580	1681	-421
2007	-4452	-9315	6609	-2651	1684	-778
2008	-4461	-9151	6635	-2710	1681	-916
2009	-4386	-8702	6656	-2722	1681	-1298
2010	**-3982**	**-7587**	**6674**	**-2757**	**1678**	**-1990**
2011	-3745	-7513	6693	-2827	1680	-1778
2012	-3398	-6924	6707	-2830	1678	-2028
2013	-3149	-6618	6721	-2860	1680	-2072
2014	-2945	-6339	6736	-2895	1680	-2126
2015	**-2622**	**-6013**	**6755**	**-2898**	**1679**	**-2146**
2016	-2398	-6027	6768	-2924	1677	-1892
2017	-2217	-6147	6780	-2979	1679	-1549
2018	-2083	-6140	6793	-3012	1678	-1402
2019	-1846	-5463	6804	-3037	1678	-1828
2020	**-1524**	**-4690**	**6820**	**-3084**	**1677**	**-2247**

B (Low) Scotland **Gg CO$_2$/year**	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	-4452	-9315	6609	-2651	1684	-778
2008	*-4807*	*-9112*	*6360*	*-2770*	*1629*	*-915*
2009	*-4730*	*-8539*	*6297*	*-2807*	*1614*	*-1295*
2010	***-4302***	***-7369***	***6303***	***-2858***	***1607***	***-1985***
2011	*-4139*	*-7308*	*6287*	*-2947*	*1598*	*-1770*
2012	*-3962*	*-6809*	*6248*	*-2969*	*1586*	*-2017*
2013	*-3944*	*-6635*	*6196*	*-3022*	*1575*	*-2057*
2014	*-3997*	*-6511*	*6141*	*-3080*	*1562*	*-2109*
2015	***-3926***	***-6327***	***6085***	***-3105***	***1548***	***-2126***
2016	*-3942*	*-6483*	*6030*	*-3153*	*1532*	*-1869*
2017	*-4017*	*-6757*	*5974*	*-3236*	*1526*	*-1524*
2018	*-4129*	*-6896*	*5923*	*-3292*	*1513*	*-1376*
2019	*-4114*	*-6348*	*5873*	*-3339*	*1500*	*-1801*
2020	***-3978***	***-5677***	***5836***	***-3410***	***1492***	***-2218***

C (High) Scotland **Gg CO$_2$/year**	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	-4452	-9315	6609	-2651	1684	-778
2008	*-4099*	*-9168*	*6905*	*-2650*	*1731*	*-916*
2009	*-3965*	*-8781*	*7007*	*-2637*	*1747*	*-1301*
2010	***-3534***	***-7692***	***7060***	***-2655***	***1750***	***-1997***
2011	*-3219*	*-7607*	*7120*	*-2707*	*1762*	*-1788*
2012	*-2738*	*-6973*	*7192*	*-2688*	*1772*	*-2041*
2013	*-2323*	*-6596*	*7272*	*-2698*	*1786*	*-2087*
2014	*-1921*	*-6235*	*7369*	*-2711*	*1801*	*-2145*
2015	***-1410***	***-5826***	***7459***	***-2692***	***1817***	***-2168***
2016	*-1004*	*-5761*	*7536*	*-2694*	*1832*	*-1916*
2017	*-642*	*-5806*	*7616*	*-2723*	*1848*	*-1576*
2018	*-333*	*-5727*	*7699*	*-2732*	*1860*	*-1432*
2019	*72*	*-4982*	*7772*	*-2734*	*1876*	*-1860*
2020	***563***	***-4143***	***7857***	***-2757***	***1887***	***-2281***

Table A1. 4: Wales data for 2006 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) Wales Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**-238**	**-1174**	**969**	**-398**	**713**	**-348**
1991	-193	-1238	978	-388	710	-256
1992	-247	-1356	985	-442	707	-141
1993	-254	-1428	986	-446	705	-71
1994	-255	-1488	993	-447	704	-16
1995	**-193**	**-1402**	**1000**	**-442**	**701**	**-50**
1996	-167	-1235	1006	-460	701	-179
1997	-112	-1067	1008	-461	703	-295
1998	-110	-992	1012	-497	702	-335
1999	-67	-836	1016	-509	699	-437
2000	**-125**	**-1435**	**1021**	**-530**	**698**	**121**
2001	-127	-1470	1024	-528	698	148
2002	-164	-1516	1029	-547	696	175
2003	-193	-1553	1035	-545	696	175
2004	-232	-1578	1038	-557	695	170
2005	**-227**	**-1509**	**1040**	**-562**	**694**	**110**
2006	-195	-1473	1045	-575	691	116
2007	-201	-1411	1050	-601	692	68
2008	-200	-1303	1053	-608	692	-35
2009	-200	-1205	1057	-616	692	-128
2010	**-34**	**-317**	**1059**	**-622**	**692**	**-846**
2011	70	-278	1062	-631	692	-775
2012	146	-338	1065	-641	692	-632
2013	204	-350	1067	-651	693	-555
2014	257	-310	1069	-659	693	-537
2015	**352**	**-202**	**1072**	**-664**	**693**	**-547**
2016	411	-186	1074	-672	693	-498
2017	466	-128	1076	-681	693	-494
2018	509	-106	1078	-689	693	-468
2019	587	145	1080	-696	694	-636
2020	**718**	**449**	**1082**	**-701**	**694**	**-806**

B (Low) Wales Gg CO$_2$/year	5 NET	5A Forestland	5B Cropland	5C Grassland	5E Settlements	5G HWP
2007	-201	-1411	1050	-601	692	68
2008	-289	-1305	1011	-631	670	-34
2009	-315	-1206	1002	-647	664	-127
2010	**-162**	**-321**	**1000**	**-658**	**661**	**-845**
2011	-80	-287	997	-673	657	-773
2012	-33	-357	990	-689	653	-629
2013	-9	-382	981	-706	648	-551
2014	7	-355	974	-721	643	-533
2015	**69**	**-257**	**965**	**-734**	**637**	**-542**
2016	96	-250	957	-749	631	-492
2017	116	-207	947	-765	628	-487
2018	123	-198	939	-780	623	-461
2019	169	43	930	-793	618	-629
2020	**276**	**343**	**922**	**-804**	**613**	**-799**

C (High) Wales Gg CO$_2$/year	5 NET	5A Forestland	5B Cropland	5C Grassland	5E Settlements	5G HWP
2007	-201	-1411	1050	-601	692	68
2008	-109	-1301	1098	-585	714	-35
2009	-81	-1203	1114	-585	721	-129
2010	**95**	**-313**	**1118**	**-587**	**724**	**-848**
2011	219	-270	1129	-589	728	-778
2012	321	-325	1141	-593	733	-636
2013	406	-330	1152	-595	738	-559
2014	489	-283	1166	-596	744	-542
2015	**615**	**-168**	**1180**	**-594**	**750**	**-552**
2016	703	-145	1193	-596	756	-504
2017	789	-81	1206	-597	762	-501
2018	859	-54	1218	-598	768	-475
2019	964	203	1229	-597	774	-644
2020	**1123**	**512**	**1241**	**-595**	**779**	**-815**

Table A1. 5: Northern Ireland data for 2006 UK GHG Inventory: A: LULUCF GPG Format – with MID projection, B: LULUCF GPG Format – with LO projection, C: LULUCF GPG Format – with HI projection (Italics are projections) (HWP = Harvested Wood Products)

A (Mid) N. Ireland Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**-30**	**-730**	**1255**	**-1079**	**570**	**-45**
1991	-36	-732	1244	-1071	569	-46
1992	-111	-759	1232	-1116	569	-37
1993	-121	-713	1216	-1118	569	-74
1994	-135	-747	1205	-1118	569	-43
1995	**-141**	**-720**	**1196**	**-1113**	**568**	**-72**
1996	-163	-706	1187	-1130	568	-82
1997	-172	-702	1175	-1129	568	-84
1998	-220	-705	1165	-1160	568	-89
1999	-244	-714	1156	-1178	568	-77
2000	**-274**	**-731**	**1149**	**-1201**	**568**	**-60**
2001	-274	-746	1142	-1204	569	-35
2002	-291	-727	1135	-1216	569	-53
2003	-290	-695	1130	-1215	569	-80
2004	-282	-688	1124	-1222	569	-65
2005	**-282**	**-633**	**1117**	**-1229**	**569**	**-107**
2006	-295	-622	1113	-1239	569	-116
2007	-286	-543	1108	-1254	569	-166
2008	-268	-496	1104	-1259	569	-187
2009	-243	-472	1100	-1265	570	-176
2010	**-251**	**-543**	**1096**	**-1271**	**570**	**-102**
2011	-241	-491	1092	-1277	570	-135
2012	-224	-433	1088	-1284	570	-165
2013	-205	-393	1085	-1291	570	-176
2014	-195	-397	1081	-1297	570	-152
2015	**-168**	**-320**	**1078**	**-1301**	**570**	**-196**
2016	-140	-248	1075	-1307	571	-232
2017	-112	-119	1073	-1313	571	-324
2018	-77	-68	1070	-1318	571	-333
2019	-44	-54	1068	-1323	571	-305
2020	**-11**	**-8**	**1066**	**-1327**	**571**	**-313**

B (Low) N. Ireland Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	-286	-543	1108	-1254	569	-166
2008	*-354*	*-493*	*1069*	*-1296*	*552*	*-187*
2009	*-346*	*-458*	*1054*	*-1314*	*548*	*-176*
2010	***-358***	***-525***	***1047***	***-1326***	***547***	***-102***
2011	*-367*	*-473*	*1036*	*-1339*	*545*	*-135*
2012	*-376*	*-423*	*1024*	*-1354*	*542*	*-165*
2013	*-390*	*-394*	*1013*	*-1371*	*538*	*-176*
2014	*-414*	*-411*	*1001*	*-1387*	*534*	*-152*
2015	***-424***	***-348***	***989***	***-1400***	***531***	***-196***
2016	*-432*	*-288*	*977*	*-1414*	*525*	*-232*
2017	*-435*	*-169*	*966*	*-1429*	*522*	*-324*
2018	*-429*	*-124*	*954*	*-1443*	*517*	*-333*
2019	*-432*	*-126*	*944*	*-1458*	*514*	*-305*
2020	***-431***	***-92***	***935***	***-1471***	***510***	***-313***

C (High) N. Ireland Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2007	-286	-543	1108	-1254	569	-166
2008	*-181*	*-497*	*1139*	*-1223*	*586*	*-187*
2009	*-134*	*-478*	*1145*	*-1217*	*591*	*-176*
2010	***-134***	***-551***	***1146***	***-1219***	***593***	***-102***
2011	*-108*	*-498*	*1148*	*-1217*	*595*	*-135*
2012	*-68*	*-435*	*1150*	*-1216*	*598*	*-165*
2013	*-22*	*-390*	*1155*	*-1214*	*603*	*-176*
2014	*19*	*-387*	*1161*	*-1210*	*607*	*-152*
2015	***74***	***-303***	***1166***	***-1204***	***612***	***-196***
2016	*131*	*-223*	*1172*	*-1201*	*616*	*-232*
2017	*190*	*-89*	*1178*	*-1196*	*620*	*-324*
2018	*253*	*-31*	*1183*	*-1192*	*625*	*-333*
2019	*316*	*-11*	*1190*	*-1186*	*628*	*-305*
2020	***378***	***40***	***1197***	***-1180***	***633***	***-313***

24.2 Appendix 2: Sectoral Tables for Land Use Change and Forestry Sector as submitted for the UK 2006 Greenhouse Gas Inventory in the format defined by IPCC LULUCF Good Practice Guidance

Table A2. 1. Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1990 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**2,929.06**	**0.80**	**0.03**	**0.20**	**6.97**
A. Forest Land	**-12,155.07**	**0.20**	**0.02**	**0.05**	**1.79**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-12,155.07	0.20	0.02	0.05	1.79
B. Cropland	**15,822.10**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,788.11	NA	NA	NO	NO
2. Land converted to Cropland	14,033.98	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,130.33**	**0.15**	**0.00**	**0.04**	**1.28**
1. Grassland remaining Grassland	1,041.48	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,171.81	0.15	0.00	0.04	1.28
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**7,074.34**	**0.45**	**0.00**	**0.11**	**3.90**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,972.27	IE	IE	0.11	3.90
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,681.97**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,681.97	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	318.80	0.59	0.00	0.15	5.18
Grassland converted to other Land-Use Categories	18,274.97	NO	NO	NO	NO

Table A2. 2 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1991 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**2,840.89**	**0.90**	**0.03**	**0.22**	**7.91**
A. Forest Land	**-12,635.55**	**0.35**	**0.02**	**0.09**	**3.02**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-12,635.55	0.35	0.02	0.09	3.02
B. Cropland	**15,978.23**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,930.08	NA	NA	NO	NO
2. Land converted to Cropland	14,048.15	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,074.88**	**0.16**	**0.00**	**0.04**	**1.37**
1. Grassland remaining Grassland	1,211.06	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,285.94	0.16	0.00	0.04	1.37
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,989.43**	**0.40**	**0.00**	**0.10**	**3.52**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,897.24	IE	IE	0.10	3.52
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,416.34**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,416.34	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	318.53	0.56	0.00	0.14	4.89
Grassland converted to other Land-Use Categories	18,124.19	NO	NO	NO	NO

Table A2. 3 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1992 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**2,284.79**	**0.62**	**0.03**	**0.15**	**5.41**
A. Forest Land	**-13,320.03**	**0.09**	**0.02**	**0.02**	**0.77**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,320.03	0.09	0.02	0.02	0.77
B. Cropland	**15,983.46**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,920.17	NA	NA	NO	NO
2. Land converted to Cropland	14,063.29	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,177.50**	**0.17**	**0.00**	**0.04**	**1.50**
1. Grassland remaining Grassland	1,215.41	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,392.91	0.17	0.00	0.04	1.50
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,907.44**	**0.36**	**0.00**	**0.09**	**3.15**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,824.95	IE	IE	0.09	3.15
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,108.57**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,108.57	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	319.13	0.53	0.00	0.13	4.65
Grassland converted to other Land-Use Categories	17,974.43	NO	NO	NO	NO

Table A2. 4 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1993 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/removals	CH_4	N_2O	NO_x	CO
	(Gg)				
Total Land-Use Categories	**1,123.70**	**0.63**	**0.02**	**0.16**	**5.48**
A. Forest Land	**-13,678.57**	**0.15**	**0.02**	**0.04**	**1.35**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,678.57	0.15	0.02	0.04	1.35
B. Cropland	**15,566.14**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,486.90	NA	NA	NO	NO
2. Land converted to Cropland	14,079.24	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,609.50**	**0.13**	**0.00**	**0.03**	**1.15**
1. Grassland remaining Grassland	925.67	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,535.17	0.13	0.00	0.03	1.15
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,848.20**	**0.34**	**0.00**	**0.08**	**2.99**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,769.90	IE	IE	0.08	2.99
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,002.57**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,002.57	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	312.28	0.47	0.00	0.12	4.14
Grassland converted to other Land-Use Categories	17,834.65	NO	NO	NO	NO

Table A2. 5 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1994 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**916.58**	**0.61**	**0.02**	**0.15**	**5.32**
A. Forest Land	**-14,164.06**	**0.12**	**0.01**	**0.03**	**1.07**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-14,164.06	0.12	0.01	0.03	1.07
B. Cropland	**15,618.32**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,522.47	NA	NA	NO	NO
2. Land converted to Cropland	14,095.85	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,547.73**	**0.14**	**0.00**	**0.03**	**1.22**
1. Grassland remaining Grassland	1,094.37	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,642.10	0.14	0.00	0.03	1.22
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,803.12**	**0.35**	**0.00**	**0.09**	**3.03**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,723.86	IE	IE	0.09	3.03
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-793.07**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-793.07	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	321.39	0.49	0.00	0.12	4.25
Grassland converted to other Land-Use Categories	17,718.50	NO	NO	NO	NO

Table A2. 6 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1995 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**1,242.37**	**1.41**	**0.02**	**0.35**	**12.31**
A. Forest Land	**-13,727.88**	**0.96**	**0.02**	**0.24**	**8.38**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,727.88	0.96	0.02	0.24	8.38
B. Cropland	**15,749.94**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,636.95	NA	NA	NO	NO
2. Land converted to Cropland	14,113.00	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,460.78**	**0.16**	**0.00**	**0.04**	**1.36**
1. Grassland remaining Grassland	1,276.78	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,737.56	0.16	0.00	0.04	1.36
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,722.26**	**0.29**	**0.00**	**0.07**	**2.57**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,654.90	IE	IE	0.07	2.57
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,041.17**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,041.17	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	318.92	0.45	0.00	0.11	3.93
Grassland converted to other Land-Use Categories	17,625.30	NO	NO	NO	NO

Table A2. 7 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1996 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/removals	CH_4	N_2O	NO_x	CO
	(Gg)				
Total Land-Use Categories	**1,000.44**	**1.02**	**0.02**	**0.25**	**8.91**
A. Forest Land	**-13,604.66**	**0.50**	**0.01**	**0.12**	**4.36**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,604.66	0.50	0.01	0.12	4.36
B. Cropland	**15,787.97**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,657.42	NA	NA	NO	NO
2. Land converted to Cropland	14,130.55	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,704.72**	**0.18**	**0.00**	**0.05**	**1.60**
1. Grassland remaining Grassland	1,122.64	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,827.36	0.18	0.00	0.05	1.60
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,707.07**	**0.34**	**0.00**	**0.08**	**2.96**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,629.61	IE	IE	0.08	2.96
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,185.22**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,185.22	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	340.86	0.52	0.00	0.13	4.56
Grassland converted to other Land-Use Categories	17,535.29	NO	NO	NO	NO

Table A2. 8 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1997 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**693.15**	**1.20**	**0.02**	**0.30**	**10.48**
A. Forest Land	**-13,360.12**	**0.65**	**0.01**	**0.16**	**5.72**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,360.12	0.65	0.01	0.16	5.72
B. Cropland	**15,529.82**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,381.41	NA	NA	NO	NO
2. Land converted to Cropland	14,148.40	NE,NO	NE,NO	NO	NO
C. Grassland	**-6,821.67**	**0.15**	**0.00**	**0.04**	**1.33**
1. Grassland remaining Grassland	1,137.86	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,959.52	0.15	0.00	0.04	1.33
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,709.90**	**0.39**	**0.00**	**0.10**	**3.44**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,619.91	IE	IE	0.10	3.44
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,364.77**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,364.77	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	351.48	0.54	0.00	0.14	4.76
Grassland converted to other Land-Use Categories	17,438.67	NO	NO	NO	NO

Table A2. 9 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1998 for United Kingdom in Sectoral Report Table Format

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/removals	CH_4	N_2O	NO_x	CO
	(Gg)				
Total Land-Use Categories	**77.02**	**0.91**	**0.02**	**0.23**	**7.94**
A. Forest Land	**-13,321.59**	**0.36**	**0.01**	**0.09**	**3.17**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,321.59	0.36	0.01	0.09	3.17
B. Cropland	**15,417.91**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,251.44	NA	NA	NO	NO
2. Land converted to Cropland	14,166.47	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,219.86**	**0.16**	**0.00**	**0.04**	**1.39**
1. Grassland remaining Grassland	837.44	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,057.30	0.16	0.00	0.04	1.39
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,669.02**	**0.39**	**0.00**	**0.10**	**3.38**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,580.49	IE	IE	0.10	3.38
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,468.47**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,468.47	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	356.50	0.54	0.00	0.14	4.77
Grassland converted to other Land-Use Categories	17,371.84	NO	NO	NO	NO

Table A2. 10 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 1999 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**-201.67**	**0.83**	**0.01**	**0.21**	**7.28**
A. Forest Land	**-13,489.27**	**0.06**	**0.01**	**0.01**	**0.50**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,489.27	0.06	0.01	0.01	0.50
B. Cropland	**15,320.53**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,135.86	NA	NA	NO	NO
2. Land converted to Cropland	14,184.66	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,124.11**	**0.39**	**0.00**	**0.10**	**3.43**
1. Grassland remaining Grassland	862.26	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,986.37	0.39	0.00	0.10	3.43
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,604.51**	**0.38**	**0.00**	**0.10**	**3.35**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,516.78	IE	IE	0.10	3.35
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,513.34**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,513.34	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	413.94	0.78	0.01	0.19	6.78
Grassland converted to other Land-Use Categories	17,323.74	NO	NO	NO	NO

Table A2. 11 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2000 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**-339.44**	**1.19**	**0.02**	**0.29**	**10.37**
A. Forest Land	**-13,755.67**	**0.20**	**0.01**	**0.05**	**1.75**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-13,755.67	0.20	0.01	0.05	1.75
B. Cropland	**15,339.05**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,135.81	NA	NA	NO	NO
2. Land converted to Cropland	14,203.24	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,221.49**	**0.59**	**0.00**	**0.15**	**5.15**
1. Grassland remaining Grassland	728.41	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,949.90	0.59	0.00	0.15	5.15
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,566.55**	**0.40**	**0.00**	**0.10**	**3.47**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,475.59	IE	IE	0.10	3.47
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,267.88**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,267.88	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	466.58	0.99	0.01	0.24	8.62
Grassland converted to other Land-Use Categories	17,319.04	NO	NO	NO	NO

Table A2. 12 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2001 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**-460.48**	**1.47**	**0.02**	**0.37**	**12.90**
A. Forest Land	**-14,280.31**	**0.28**	**0.01**	**0.07**	**2.42**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-14,280.31	0.28	0.01	0.07	2.42
B. Cropland	**15,286.51**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,064.76	NA	NA	NO	NO
2. Land converted to Cropland	14,221.75	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,175.78**	**0.77**	**0.01**	**0.19**	**6.78**
1. Grassland remaining Grassland	746.58	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,922.37	0.77	0.01	0.19	6.78
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,543.21**	**0.42**	**0.00**	**0.11**	**3.71**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,446.17	IE	IE	0.11	3.71
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-834.11**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-834.11	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	519.56	1.20	0.01	0.30	10.49
Grassland converted to other Land-Use Categories	17,329.46	NO	NO	NO	NO

Table A2. 13 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2002 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/removals	CH_4	N_2O	NO_x	CO
	(Gg)				
Total Land-Use Categories	**-977.63**	**1.27**	**0.02**	**0.32**	**11.11**
A. Forest Land	**-14,986.41**	**0.23**	**0.01**	**0.06**	**2.05**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-14,986.41	0.23	0.01	0.06	2.05
B. Cropland	**15,312.53**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,072.39	NA	NA	NO	NO
2. Land converted to Cropland	14,240.14	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,511.89**	**0.67**	**0.00**	**0.17**	**5.89**
1. Grassland remaining Grassland	563.60	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,075.49	0.67	0.00	0.17	5.89
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,474.94**	**0.36**	**0.00**	**0.09**	**3.17**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,391.92	IE	IE	0.09	3.17
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-266.79**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-266.79	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	486.22	1.04	0.01	0.26	9.06
Grassland converted to other Land-Use Categories	17,316.04	NO	NO	NO	NO

Table A2. 14 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2003 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**-1,029.64**	**1.21**	**0.02**	**0.30**	**10.58**
A. Forest Land	**-15,595.04**	**0.20**	**0.01**	**0.05**	**1.73**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-15,595.04	0.20	0.01	0.05	1.73
B. Cropland	**15,384.30**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,125.93	NA	NA	NO	NO
2. Land converted to Cropland	14,258.37	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,320.87**	**0.63**	**0.00**	**0.16**	**5.55**
1. Grassland remaining Grassland	872.17	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,193.04	0.63	0.00	0.16	5.55
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,459.58**	**0.38**	**0.00**	**0.09**	**3.30**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,373.17	IE	IE	0.09	3.30
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**42.39**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	42.39	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	484.45	1.01	0.01	0.25	8.85
Grassland converted to other Land-Use Categories	17,265.01	NO	NO	NO	NO

Table A2. 15 Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2004 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/removals	CH_4	N_2O	NO_x	CO
	(Gg)				
Total Land-Use Categories	**-1,771.16**	**1.18**	**0.01**	**0.29**	**10.35**
A. Forest Land	**-16,238.04**	**0.26**	**0.01**	**0.06**	**2.29**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-16,238.04	0.26	0.01	0.06	2.29
B. Cropland	**15,315.52**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,039.12	NA	NA	NO	NO
2. Land converted to Cropland	14,276.40	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,640.07**	**0.57**	**0.00**	**0.14**	**4.95**
1. Grassland remaining Grassland	685.50	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,325.58	0.57	0.00	0.14	4.95
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,422.96**	**0.36**	**0.00**	**0.09**	**3.12**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,341.31	IE	IE	0.09	3.12
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**368.48**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	368.48	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	467.53	0.92	0.01	0.23	8.07
Grassland converted to other Land-Use Categories	17,221.49	NO	NO	NO	NO

Table A2. 16. Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2005 for United Kingdom in Sectoral Report Table Format.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**-1,933.61**	**0.96**	**0.01**	**0.24**	**8.43**
A. Forest Land	**-15,721.42**	**0.06**	**0.01**	**0.01**	**0.49**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-15,721.42	0.06	0.01	0.01	0.49
B. Cropland	**15,233.03**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	938.83	NA	NA	NO	NO
2. Land converted to Cropland	14,294.20	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,689.08**	**0.57**	**0.00**	**0.14**	**4.99**
1. Grassland remaining Grassland	717.76	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,406.84	0.57	0.00	0.14	4.99
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,384.15**	**0.34**	**0.00**	**0.08**	**2.95**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,306.83	IE	IE	0.08	2.95
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-140.27**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-140.27	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	467.54	0.91	0.01	0.23	7.94
Grassland converted to other Land-Use Categories	17,163.90	NO	NO	NO	NO

Table A2. 17. Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2006 for United Kingdom in Sectoral Report Table Format

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/removals	CH_4	N_2O	NO_x	CO
	(Gg)				
Total Land-Use Categories	**-1,816.47**	**1.44**	**0.01**	**0.36**	**12.59**
A. Forest Land	**-15,090.61**	**0.64**	**0.01**	**0.16**	**5.58**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-15,090.61	0.64	0.01	0.16	5.58
B. Cropland	**15,279.27**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	967.54	NA	NA	NO	NO
2. Land converted to Cropland	14,311.73	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,789.54**	**0.51**	**0.00**	**0.13**	**4.48**
1. Grassland remaining Grassland	734.88	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,524.42	0.51	0.00	0.13	4.48
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,328.71**	**0.29**	**0.00**	**0.07**	**2.52**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,262.67	IE	IE	0.07	2.52
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-544.29**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-544.29	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	446.30	0.80	0.01	0.20	7.01
Grassland converted to other Land-Use Categories	17,075.82	NO	NO	NO	NO

Table A2. 18. Emissions and Removals by Land Use, Land Use Change and Forestry (Sector 5) in 2007 for United Kingdom in Sectoral Report Table Format

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Net CO_2 emissions/removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
	(Gg)				
Total Land-Use Categories	**-1,815.00**	**1.47**	**0.01**	**0.36**	**12.84**
A. Forest Land	**-14,173.38**	**0.73**	**0.01**	**0.18**	**6.37**
1. Forest Land remaining Forest Land	IE,NO	IE,NE,NO	IE,NE,NO	NO	NO
2. Land converted to Forest Land	-14,173.38	0.73	0.01	0.18	6.37
B. Cropland	**15,288.35**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	959.37	NA	NA	NO	NO
2. Land converted to Cropland	14,328.98	NE,NO	NE,NO	NO	NO
C. Grassland	**-7,967.05**	**0.43**	**0.00**	**0.11**	**3.78**
1. Grassland remaining Grassland	700.62	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,667.67	0.43	0.00	0.11	3.78
D. Wetlands	**IE,NE,NO**	**IE,NE,NO**	**IE,NE,NO**	**NO**	**NO**
1. Wetlands remaining Wetlands	IE,NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Wetlands	IE,NE,NO	IE,NE,NO	IE,NE,NO	NO	NO
E. Settlements	**6,329.81**	**0.31**	**0.00**	**0.08**	**2.69**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,259.39	IE	IE	0.08	2.69
F. Other Land	**NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land					
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,292.74**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,292.74	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	435.29	0.74	0.01	0.18	6.47
Grassland converted to other Land-Use Categories	17,003.28	NO	NO	NO	NO

24.3 Appendix 3: Sectoral Tables for the LULUCF Sector for the Devolved Administration Regions

Table A3. 1: United Kingdom

UK			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CO2**	**2,929**	**2,841**	**1,950**	**1,124**	**917**	**1,242**	**1,000**	**693**	**77**	**-202**	**-339**	**-460**	**-978**	**-1,030**	**-1,771**	**-1,934**	**-1,816**	**-1,815**
5A	Forest Land	Gg CO2	**-12,155**	**-12,636**	**-13,320**	**-13,679**	**-14,164**	**-13,728**	**-13,605**	**-13,360**	**-13,322**	**-13,489**	**-13,756**	**-14,280**	**-14,986**	**-15,595**	**-16,238**	**-15,721**	**-15,091**	**-14,173**
5A1	Forest-Land remaining Forest-Land	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5A2	Land converted to Forest-Land	Gg CO2	-12,155	-12,636	-13,320	-13,679	-14,164	-13,728	-13,605	-13,360	-13,322	-13,489	-13,756	-14,280	-14,986	-15,595	-16,238	-15,721	-15,091	-14,173
5B	**Cropland**	**Gg CO2**	**15,822**	**15,978**	**15,983**	**15,566**	**15,618**	**15,750**	**15,788**	**15,530**	**15,418**	**15,321**	**15,339**	**15,287**	**15,313**	**15,384**	**15,316**	**15,233**	**15,279**	**15,288**
5B1	Cropland remaining Cropland	Gg CO2	1,010	973	936	900	863	826	790	753	716	680	643	621	599	577	555	533	511	489
5B2	Land converted to Cropland	Gg CO2	14,034	14,048	14,063	14,079	14,096	14,113	14,131	14,148	14,166	14,185	14,203	14,222	14,240	14,258	14,276	14,294	14,312	14,329
5B (liming)	*Liming of Cropland*	*Gg CO2*	*779*	*957*	*984*	*587*	*660*	*811*	*868*	*628*	*535*	*456*	*493*	*444*	*473*	*549*	*484*	*406*	*457*	*470*
5C	**Grassland**	**Gg CO2**	**-6,130**	**-6,075**	**-6,512**	**-6,609**	**-6,548**	**-6,461**	**-6,705**	**-6,822**	**-7,220**	**-7,124**	**-7,221**	**-7,176**	**-7,512**	**-7,321**	**-7,640**	**-7,689**	**-7,790**	**-7,967**
5C1	Grassland remaining Grassland	Gg CO2	390	396	390	383	484	558	475	420	315	432	427	466	298	503	355	404	422	431
5C2	Land converted to Grassland	Gg CO2	-7,205	-7,322	-7,432	-7,565	-7,674	-7,773	-7,869	-7,994	-8,094	-8,076	-8,085	-8,100	-8,230	-8,338	-8,455	-8,537	-8,642	-8,767
5C (liming)	*Liming of Grassland*	*Gg CO2*	*652*	*815*	*491*	*543*	*610*	*719*	*647*	*718*	*523*	*431*	*301*	*281*	*265*	*369*	*331*	*313*	*313*	*270*
5C2	Biomass loss from deforestation to products	GgCO2	24	26	28	22	23	26	30	25	26	65	97	128	111	104	93	94	84	71
5D	**Wetland**	**Gg CO2**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	Wetland remaining Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**7,074**	**6,989**	**6,907**	**6,848**	**6,803**	**6,722**	**6,707**	**6,710**	**6,669**	**6,605**	**6,567**	**6,543**	**6,475**	**6,460**	**6,423**	**6,384**	**6,329**	**6,330**
5E1	Settlements remaining Settlements	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5E2	Land converted to Settlements	Gg CO2	*6,972*	*6,897*	*6,825*	*6,770*	*6,724*	*6,655*	*6,630*	*6,620*	*6,580*	*6,517*	*6,476*	*6,446*	*6,392*	*6,373*	*6,341*	*6,307*	*6,263*	*6,259*
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	102	92	82	78	79	67	77	90	89	88	91	97	83	86	82	77	66	70
5F	**Other-Land**	**Gg CO2**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
5F1	Other-Land remaining Other-land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-1,682**	**-1,416**	**-1,109**	**-1,003**	**-793**	**-1,041**	**-1,185**	**-1,365**	**-1,468**	**-1,513**	**-1,268**	**-834**	**-267**	**42**	**368**	**-140**	**-544**	**-1,293**
5G1	Harvested Wood Products	Gg CO2	-1,682	-1,416	-1,109	-1,003	-793	-1,041	-1,185	-1,365	-1,468	-1,513	-1,268	-834	-267	42	368	-140	-544	-1,293
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	319	319	319	312	321	319	341	351	356	414	467	520	486	484	468	468	446	435
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	18,275	18,124	17,974	17,835	17,719	17,625	17,535	17,439	17,372	17,324	17,319	17,329	17,316	17,265	17,221	17,164	17,076	17,003

UK			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CH4**	**0.797**	**0.904**	**0.619**	**0.626**	**0.608**	**1.407**	**1.019**	**1.198**	**0.907**	**0.832**	**1.185**	**1.474**	**1.269**	**1.209**	**1.183**	**0.964**	**1.438**	**1.467**
5A2	Forest wildfires	Gg CH4	0.205	0.345	0.087	0.154	0.122	0.957	0.498	0.654	0.362	0.057	0.200	0.276	0.234	0.197	0.261	0.057	0.638	0.728
5C2	Land converted to Grassland	Gg CH4	0.147	0.156	0.171	0.131	0.140	0.155	0.183	0.152	0.158	0.392	0.589	0.775	0.673	0.634	0.566	0.570	0.512	0.432
5E2	Land converted to Settlements	Gg CH4	0.445	0.402	0.360	0.342	0.346	0.294	0.338	0.393	0.386	0.383	0.397	0.423	0.362	0.377	0.356	0.337	0.288	0.307
Information Item	Forest Land converted to other Land-Use Categories	Gg CH4	0.592	0.559	0.531	0.473	0.485	0.449	0.521	0.544	0.545	0.775	0.985	1.198	1.036	1.011	0.922	0.907	0.801	0.739
Information Item	Grassland converted to other Land-Use Categories	Gg CH4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg N2O**	**0.026**	**0.027**	**0.025**	**0.019**	**0.017**	**0.022**	**0.018**	**0.018**	**0.016**	**0.015**	**0.017**	**0.018**	**0.016**	**0.015**	**0.014**	**0.012**	**0.014**	**0.014**
5A2	N fertilisation of forests	Gg N2O	0.021	0.022	0.021	0.014	0.013	0.013	0.011	0.010	0.010	0.009	0.009	0.008	0.007	0.007	0.006	0.005	0.004	0.004
5A2	Forest wildfires	Gg N2O	0.001	0.002	0.001	0.001	0.001	0.007	0.003	0.004	0.002	0.000	0.001	0.002	0.002	0.001	0.002	0.000	0.004	0.005
5C2	Land converted to Grassland	Gg N2O	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.003
5E2	Land converted to Settlements	Gg N2O	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.002	0.002	0.002	0.002
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.004	0.003	0.004	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.007	0.008	0.007	0.007	0.006	0.006	0.006	0.005
Information Item	Grassland converted to other Land-Use Categories	Gg N2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg NOx**	**0.198**	**0.225**	**0.154**	**0.156**	**0.151**	**0.350**	**0.253**	**0.298**	**0.225**	**0.207**	**0.294**	**0.366**	**0.315**	**0.300**	**0.294**	**0.239**	**0.357**	**0.333**
5A2	Forest wildfires	Gg NOx	0.051	0.086	0.022	0.038	0.030	0.238	0.124	0.162	0.090	0.014	0.050	0.069	0.058	0.049	0.065	0.014	0.158	0.181
5C2	Land converted to Grassland	Gg NOx	0.036	0.039	0.043	0.033	0.035	0.039	0.045	0.038	0.039	0.097	0.146	0.193	0.167	0.158	0.141	0.142	0.127	0.076
5E2	Land converted to Settlements	Gg NOx	0.111	0.100	0.089	0.085	0.086	0.073	0.084	0.098	0.096	0.095	0.099	0.105	0.090	0.094	0.089	0.084	0.072	0.076
Information Item	Forest Land converted to other Land-Use Categories	Gg NOx	0.147	0.139	0.132	0.117	0.121	0.112	0.129	0.135	0.135	0.193	0.245	0.298	0.257	0.251	0.229	0.225	0.199	0.153
Information Item	Grassland converted to other Land-Use Categories	Gg NOx	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg CO**	**6.970**	**7.909**	**5.413**	**5.481**	**5.319**	**12.308**	**8.913**	**10.483**	**7.935**	**7.282**	**10.370**	**12.901**	**11.106**	**10.575**	**10.353**	**8.433**	**12.585**	**11.744**
5A2	Forest wildfires	Gg CO	1.791	3.020	0.765	1.345	1.071	8.377	4.355	5.719	3.168	0.500	1.748	2.416	2.045	1.726	2.285	0.495	5.580	6.366
5C2	Land converted to Grassland	Gg CO	1.282	1.369	1.498	1.146	1.221	1.359	1.600	1.328	1.387	3.432	5.150	6.780	5.891	5.550	4.950	4.987	4.484	2.689
5E2	Land converted to Settlements	Gg CO	3.897	3.520	3.150	2.990	3.027	2.572	2.958	3.436	3.380	3.350	3.473	3.705	3.170	3.299	3.118	2.952	2.522	2.689
Information Item	Forest Land converted to other Land-Use Categories	Gg CO	5.180	4.889	4.647	4.136	4.248	3.930	4.558	4.764	4.767	6.782	8.623	10.485	9.061	8.849	8.067	7.939	7.006	5.378
Information Item	Grassland converted to other Land-Use Categories	Gg CO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table A3. 2 : England

England			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CO2**	**5,725**	**5,853**	**5,479**	**5,023**	**5,020**	**5,200**	**4,960**	**4,639**	**4,229**	**4,030**	**3,972**	**3,918**	**3,634**	**3,655**	**3,350**	**3,162**	**3,137**	**3,124**
5A	Forest Land	Gg CO2	**-2,716**	**-2,741**	**-2,847**	**-2,836**	**-2,877**	**-2,722**	**-2,846**	**-2,809**	**-2,781**	**-2,869**	**-2,739**	**-2,923**	**-3,151**	**-3,313**	**-3,520**	**-3,447**	**-3,253**	**-2,905**
5A1	Forest-Land remaining Forest-Land	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5A2	Land converted to Forest-Land	Gg CO2	-2,716	-2,741	-2,847	-2,836	-2,877	-2,722	-2,846	-2,809	-2,781	-2,869	-2,739	-2,923	-3,151	-3,313	-3,520	-3,447	-3,253	-2,905
5B	**Cropland**	**Gg CO2**	**7,496**	**7,581**	**7,545**	**7,168**	**7,173**	**7,241**	**7,236**	**6,992**	**6,869**	**6,757**	**6,742**	**6,658**	**6,662**	**6,695**	**6,615**	**6,507**	**6,522**	**6,521**
5B1	Cropland remaining Cropland	Gg CO2	1,125	1,088	1,051	1,015	978	941	905	868	831	795	758	736	714	692	670	648	626	604
5B2	Land converted to Cropland	Gg CO2	5,745	5,722	5,701	5,681	5,663	5,647	5,632	5,619	5,607	5,596	5,586	5,577	5,569	5,561	5,555	5,549	5,543	5,538
5B (liming)	*Liming of Cropland*	*Gg CO2*	*626*	*771*	*793*	*472*	*531*	*652*	*699*	*505*	*431*	*367*	*398*	*345*	*379*	*441*	*390*	*310*	*352*	*379*
5C	**Grassland**	**Gg CO2**	**-2,549**	**-2,502**	**-2,759**	**-2,814**	**-2,775**	**-2,725**	**-2,860**	**-2,917**	**-3,128**	**-3,048**	**-3,058**	**-2,952**	**-3,190**	**-3,141**	**-3,280**	**-3,307**	**-3,396**	**-3,461**
5C1	Grassland remaining Grassland	Gg CO2	228	245	220	218	281	322	268	251	191	250	257	298	175	251	184	189	175	233
5C2	Land converted to Grassland	Gg CO2	-3,154	-3,214	-3,270	-3,342	-3,398	-3,446	-3,493	-3,561	-3,610	-3,576	-3,561	-3,551	-3,623	-3,680	-3,744	-3,782	-3,837	-3,907
5C (liming)	*Liming of Grassland*	*Gg CO2*	*353*	*441*	*263*	*288*	*319*	*373*	*335*	*369*	*265*	*214*	*150*	*174*	*147*	*184*	*186*	*192*	*182*	*142*
5C2	Biomass loss from deforestation to products	GgCO2	24	26	28	22	23	26	30	25	26	65	97	128	111	104	93	94	84	71
5D	**Wetland**	**Gg CO2**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	Wetland remaining Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**4,017**	**3,948**	**3,881**	**3,831**	**3,792**	**3,727**	**3,709**	**3,705**	**3,670**	**3,618**	**3,585**	**3,564**	**3,510**	**3,494**	**3,463**	**3,431**	**3,387**	**3,384**
5E1	Settlements remaining Settlements	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5E2	Land converted to Settlements	Gg CO2	*3,944*	*3,882*	*3,822*	*3,775*	*3,735*	*3,678*	*3,654*	*3,641*	*3,606*	*3,555*	*3,520*	*3,494*	*3,450*	*3,432*	*3,405*	*3,376*	*3,340*	*3,333*
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	73	66	59	56	57	48	56	65	64	63	65	70	60	62	59	56	47	51
5F	**Other-Land**	**Gg CO2**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
5F1	Other-Land remaining Other-land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-524**	**-433**	**-342**	**-327**	**-292**	**-321**	**-279**	**-333**	**-401**	**-428**	**-559**	**-429**	**-197**	**-79**	**72**	**-21**	**-123**	**-417**
5G1	Harvested Wood Products	Gg CO2	-524	-433	-342	-327	-292	-321	-279	-333	-401	-428	-559	-429	-197	-79	72	-21	-123	-417
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	150	154	159	158	168	169	188	199	205	249	290	330	308	309	299	301	287	281
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	7,896	7,863	7,830	7,797	7,773	7,747	7,717	7,683	7,651	7,627	7,607	7,596	7,585	7,572	7,557	7,536	7,507	7,469

England			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CH4**	**0.498**	**0.552**	**0.419**	**0.405**	**0.402**	**0.774**	**0.585**	**0.662**	**0.554**	**0.581**	**0.797**	**0.962**	**0.824**	**0.813**	**0.751**	**0.655**	**0.848**	**0.825**
5A2	Forest wildfires	Gg CH4	0.073	0.151	0.038	0.066	0.053	0.451	0.211	0.271	0.163	0.024	0.089	0.101	0.081	0.086	0.089	0.003	0.273	0.294
5C2	Land converted to Grassland	Gg CH4	0.105	0.112	0.123	0.094	0.100	0.112	0.131	0.109	0.114	0.282	0.423	0.556	0.484	0.456	0.406	0.409	0.368	0.310
5E2	Land converted to Settlements	Gg CH4	0.320	0.289	0.259	0.245	0.248	0.211	0.243	0.282	0.277	0.275	0.285	0.304	0.260	0.271	0.256	0.242	0.207	0.221
Information Item	Forest Land converted to other Land-Use Categories	Gg CH4	0.425	0.401	0.381	0.339	0.349	0.323	0.374	0.391	0.391	0.557	0.708	0.861	0.744	0.726	0.662	0.652	0.575	0.531
Information Item	Grassland converted to other Land-Use Categories	Gg CH4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg N2O**	**0.0049**	**0.0056**	**0.0046**	**0.0053**	**0.0057**	**0.0079**	**0.0067**	**0.0075**	**0.0064**	**0.0066**	**0.0082**	**0.0093**	**0.0084**	**0.0086**	**0.0078**	**0.0072**	**0.0081**	**0.0075**
5A2	N fertilisation of forests	Gg N2O	0.0014	0.0018	0.0017	0.0025	0.0030	0.0026	0.0027	0.0029	0.0026	0.0026	0.0028	0.0027	0.0028	0.0030	0.0027	0.0027	0.0023	0.0018
5A2	Forest wildfires	Gg N2O	0.0005	0.0010	0.0003	0.0005	0.0004	0.0031	0.0015	0.0019	0.0011	0.0002	0.0006	0.0007	0.0006	0.0006	0.0006	0.0000	0.0019	0.0020
5C2	Land converted to Grassland	Gg N2O	0.0007	0.0008	0.0008	0.0006	0.0007	0.0008	0.0009	0.0007	0.0008	0.0019	0.0029	0.0038	0.0033	0.0031	0.0028	0.0028	0.0025	0.0021
5E2	Land converted to Settlements	Gg N2O	0.0022	0.0020	0.0018	0.0017	0.0017	0.0015	0.0017	0.0019	0.0019	0.0019	0.0020	0.0021	0.0018	0.0019	0.0018	0.0017	0.0014	0.0015
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.0029	0.0028	0.0026	0.0023	0.0024	0.0022	0.0026	0.0027	0.0027	0.0038	0.0049	0.0059	0.0051	0.0050	0.0046	0.0045	0.0040	0.0037
Information Item	Grassland converted to other Land-Use Categories	Gg N2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg NOx**	**0.124**	**0.137**	**0.104**	**0.101**	**0.100**	**0.192**	**0.145**	**0.165**	**0.138**	**0.144**	**0.198**	**0.239**	**0.205**	**0.202**	**0.187**	**0.163**	**0.211**	**0.183**
5A2	Forest wildfires	Gg NOx	0.018	0.037	0.009	0.016	0.013	0.112	0.052	0.067	0.040	0.006	0.022	0.025	0.020	0.021	0.022	0.001	0.068	0.073
5C2	Land converted to Grassland	Gg NOx	0.026	0.028	0.031	0.023	0.025	0.028	0.033	0.027	0.028	0.070	0.105	0.138	0.120	0.113	0.101	0.102	0.091	0.055
5E2	Land converted to Settlements	Gg NOx	0.079	0.072	0.064	0.061	0.062	0.052	0.060	0.070	0.069	0.068	0.071	0.076	0.065	0.067	0.064	0.060	0.051	0.055
Information Item	Forest Land converted to other Land-Use Categories	Gg NOx	0.106	0.100	0.095	0.084	0.087	0.080	0.093	0.097	0.097	0.138	0.176	0.214	0.185	0.180	0.165	0.162	0.143	0.110
Information Item	Grassland converted to other Land-Use Categories	Gg NOx	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg CO**	**4.358**	**4.829**	**3.669**	**3.547**	**3.514**	**6.771**	**5.119**	**5.794**	**4.846**	**5.080**	**6.971**	**8.416**	**7.212**	**7.112**	**6.569**	**5.729**	**7.416**	**6.432**
5A2	Forest wildfires	Gg CO	0.638	1.318	0.331	0.577	0.463	3.948	1.846	2.373	1.422	0.210	0.779	0.886	0.705	0.756	0.775	0.027	2.384	2.570
5C2	Land converted to Grassland	Gg CO	0.921	0.983	1.076	0.823	0.877	0.976	1.149	0.954	0.996	2.465	3.698	4.869	4.231	3.986	3.555	3.581	3.220	1.931
5E2	Land converted to Settlements	Gg CO	2.799	2.528	2.262	2.147	2.174	1.847	2.124	2.468	2.428	2.406	2.494	2.661	2.276	2.370	2.239	2.120	1.811	1.931
Information Item	Forest Land converted to other Land-Use Categories	Gg CO	3.720	3.511	3.338	2.970	3.051	2.823	3.273	3.421	3.424	4.871	6.193	7.530	6.507	6.355	5.794	5.702	5.031	3.862
Information Item	Grassland converted to other Land-Use Categories	Gg CO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table A3. 3 : Scotland

Scotland			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CO2**	**-2,528**	**-2,784**	**-3,171**	**-3,524**	**-3,714**	**-3,624**	**-3,630**	**-3,661**	**-3,822**	**-3,920**	**-3,912**	**-3,978**	**-4,157**	**-4,202**	**-4,607**	**-4,586**	**-4,463**	**-4,452**
5A	Forest Land	Gg CO2	**-7,535**	**-7,925**	**-8,358**	**-8,702**	**-9,052**	**-8,885**	**-8,818**	**-8,781**	**-8,845**	**-9,070**	**-8,850**	**-9,141**	**-9,593**	**-10,034**	**-10,452**	**-10,132**	**-9,742**	**-9,315**
5A1	Forest-Land remaining Forest-Land	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5A2	Land converted to Forest-Land	Gg CO2	-7,535	-7,925	-8,358	-8,702	-9,052	-8,885	-8,818	-8,781	-8,845	-9,070	-8,850	-9,141	-9,593	-10,034	-10,452	-10,132	-9,742	-9,315
5B	**Cropland**	**Gg CO2**	**6,102**	**6,175**	**6,222**	**6,197**	**6,248**	**6,313**	**6,359**	**6,354**	**6,372**	**6,391**	**6,427**	**6,462**	**6,486**	**6,524**	**6,539**	**6,569**	**6,600**	**6,609**
5B1	Cropland remaining Cropland	Gg CO2	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79	-79
5B2	Land converted to Cropland	Gg CO2	6,049	6,093	6,136	6,177	6,216	6,254	6,291	6,326	6,360	6,392	6,423	6,453	6,482	6,509	6,536	6,561	6,585	6,609
5B (liming)	*Liming of Cropland*	*Gg CO2*	*132*	*161*	*165*	*99*	*110*	*137*	*147*	*107*	*91*	*78*	*83*	*88*	*83*	*94*	*82*	*86*	*93*	*79*
5C	**Grassland**	**Gg CO2**	**-2,104**	**-2,115**	**-2,196**	**-2,231**	**-2,207**	**-2,180**	**-2,255**	**-2,315**	**-2,435**	**-2,389**	**-2,433**	**-2,493**	**-2,558**	**-2,420**	**-2,580**	**-2,591**	**-2,580**	**-2,651**
5C1	Grassland remaining Grassland	Gg CO2	60	49	68	63	102	134	106	68	22	80	69	66	22	151	69	114	145	96
5C2	Land converted to Grassland	Gg CO2	-2,308	-2,343	-2,377	-2,417	-2,451	-2,483	-2,514	-2,553	-2,585	-2,591	-2,604	-2,618	-2,658	-2,693	-2,730	-2,759	-2,794	-2,833
5C (liming)	*Liming of Grassland*	*Gg CO2*	*137*	*171*	*105*	*116*	*135*	*161*	*144*	*162*	*120*	*102*	*72*	*19*	*43*	*89*	*51*	*25*	*42*	*63*
5C2	Biomass loss from deforestation to products	GgCO2	8	8	9	7	7	8	9	8	8	20	30	40	35	33	29	29	26	22
5D	**Wetland**	**Gg CO2**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	Wetland remaining Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**1,774**	**1,762**	**1,750**	**1,743**	**1,739**	**1,726**	**1,728**	**1,733**	**1,729**	**1,719**	**1,714**	**1,713**	**1,701**	**1,701**	**1,696**	**1,691**	**1,681**	**1,684**
5E1	Settlements remaining Settlements	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5E2	Land converted to Settlements	Gg CO2	*1,751*	*1,741*	*1,732*	*1,725*	*1,721*	*1,711*	*1,710*	*1,713*	*1,709*	*1,699*	*1,694*	*1,691*	*1,682*	*1,682*	*1,678*	*1,673*	*1,666*	*1,668*
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	23	21	19	18	18	15	17	20	20	20	20	22	19	19	18	17	15	16
5F	**Other-Land**	**Gg CO2**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
5F1	Other-Land remaining Other-land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-765**	**-682**	**-589**	**-531**	**-442**	**-598**	**-644**	**-652**	**-644**	**-571**	**-771**	**-519**	**-192**	**26**	**191**	**-122**	**-421**	**-778**
5G1	Harvested Wood Products	Gg CO2	-765	-682	-589	-531	-442	-598	-644	-652	-644	-571	-771	-519	-192	26	191	-122	-421	-778
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	88	87	86	84	85	84	88	90	91	103	114	126	118	117	113	113	107	105
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	7,487	7,367	7,252	7,146	7,049	6,987	6,942	6,892	6,865	6,846	6,827	6,838	6,838	6,803	6,775	6,741	6,680	6,646

Scotland			**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
5	**Total Land-Use Categories**	**Gg CH4**	**0.188**	**0.242**	**0.149**	**0.160**	**0.153**	**0.486**	**0.301**	**0.365**	**0.268**	**0.196**	**0.305**	**0.367**	**0.312**	**0.314**	**0.297**	**0.207**	**0.465**	**0.479**
5A2	Forest wildfires	Gg CH4	0.055	0.117	0.030	0.053	0.044	0.385	0.184	0.242	0.145	0.022	0.084	0.097	0.079	0.086	0.090	0.003	0.285	0.312
5C2	Land converted to Grassland	Gg CH4	0.033	0.035	0.039	0.029	0.031	0.035	0.041	0.034	0.036	0.088	0.132	0.174	0.151	0.143	0.127	0.128	0.115	0.097
5E2	Land converted to Settlements	Gg CH4	0.100	0.091	0.081	0.077	0.078	0.066	0.076	0.088	0.087	0.086	0.089	0.095	0.082	0.085	0.080	0.076	0.065	0.069
Information Item	Forest Land converted to other Land-Use Categories	Gg CH4	0.133	0.126	0.120	0.106	0.109	0.101	0.117	0.122	0.123	0.174	0.222	0.270	0.233	0.228	0.207	0.204	0.180	0.166
Information Item	Grassland converted to other Land-Use Categories	Gg CH4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg N2O**	**0.0198**	**0.0210**	**0.0197**	**0.0123**	**0.0102**	**0.0130**	**0.0096**	**0.0090**	**0.0092**	**0.0073**	**0.0081**	**0.0075**	**0.0062**	**0.0060**	**0.0052**	**0.0037**	**0.0050**	**0.0053**
5A2	N fertilisation of forests	Gg N2O	0.0186	0.0194	0.0187	0.0112	0.0091	0.0097	0.0075	0.0065	0.0074	0.0059	0.0060	0.0050	0.0041	0.0039	0.0031	0.0023	0.0018	0.0020
5A2	Forest wildfires	Gg N2O	0.0004	0.0008	0.0002	0.0004	0.0003	0.0026	0.0013	0.0017	0.0010	0.0002	0.0006	0.0007	0.0005	0.0006	0.0006	0.0000	0.0020	0.0021
5C2	Land converted to Grassland	Gg N2O	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0006	0.0009	0.0012	0.0010	0.0010	0.0009	0.0009	0.0008	0.0007
5E2	Land converted to Settlements	Gg N2O	0.0007	0.0006	0.0006	0.0005	0.0005	0.0005	0.0005	0.0006	0.0006	0.0006	0.0006	0.0007	0.0006	0.0006	0.0006	0.0005	0.0004	0.0005
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.0009	0.0009	0.0008	0.0007	0.0008	0.0007	0.0008	0.0008	0.0008	0.0012	0.0015	0.0019	0.0016	0.0016	0.0014	0.0014	0.0012	0.0011
Information Item	Grassland converted to other Land-Use Categories	Gg N2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg NOx**	**0.047**	**0.060**	**0.037**	**0.040**	**0.038**	**0.121**	**0.075**	**0.091**	**0.067**	**0.049**	**0.076**	**0.091**	**0.078**	**0.078**	**0.074**	**0.052**	**0.116**	**0.119**
5A2	Forest wildfires	Gg NOx	0.014	0.029	0.007	0.013	0.011	0.096	0.046	0.060	0.036	0.005	0.021	0.024	0.020	0.021	0.022	0.001	0.071	0.078
5C2	Land converted to Grassland	Gg NOx	0.008	0.009	0.010	0.007	0.008	0.009	0.010	0.008	0.009	0.022	0.033	0.043	0.038	0.035	0.032	0.032	0.029	0.024
5E2	Land converted to Settlements	Gg NOx	0.025	0.022	0.020	0.019	0.019	0.016	0.019	0.022	0.022	0.021	0.022	0.024	0.020	0.021	0.020	0.019	0.016	0.017
Information Item	Forest Land converted to other Land-Use Categories	Gg NOx	0.033	0.031	0.030	0.026	0.027	0.025	0.029	0.030	0.030	0.043	0.055	0.067	0.058	0.057	0.052	0.051	0.045	0.041
Information Item	Grassland converted to other Land-Use Categories	Gg NOx	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg CO**	**1.646**	**2.121**	**1.307**	**1.397**	**1.342**	**4.256**	**2.638**	**3.190**	**2.344**	**1.718**	**2.673**	**3.207**	**2.730**	**2.745**	**2.601**	**1.815**	**4.072**	**4.188**
5A2	Forest wildfires	Gg CO	0.481	1.021	0.261	0.467	0.386	3.372	1.612	2.118	1.272	0.192	0.732	0.848	0.691	0.754	0.786	0.028	2.496	2.733
5C2	Land converted to Grassland	Gg CO	0.288	0.308	0.337	0.258	0.275	0.306	0.360	0.299	0.312	0.772	1.159	1.525	1.326	1.249	1.114	1.122	1.009	0.851
5E2	Land converted to Settlements	Gg CO	0.877	0.792	0.709	0.673	0.681	0.579	0.665	0.773	0.761	0.754	0.781	0.834	0.713	0.742	0.701	0.664	0.567	0.605
Information Item	Forest Land converted to other Land-Use Categories	Gg CO	1.165	1.100	1.046	0.931	0.956	0.884	1.025	1.072	1.073	1.526	1.940	2.359	2.039	1.991	1.815	1.786	1.576	1.456
Information Item	Grassland converted to other Land-Use Categories	Gg CO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table A3. 4 : Wales

Wales			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CO2**	**-238**	**-193**	**-247**	**-254**	**-255**	**-193**	**-167**	**-112**	**-110**	**-67**	**-125**	**-127**	**-164**	**-193**	**-232**	**-227**	**-195**	**-201**
5A	Forest Land	Gg CO2	**-1,174**	**-1,238**	**-1,356**	**-1,428**	**-1,488**	**-1,402**	**-1,235**	**-1,067**	**-992**	**-836**	**-1,435**	**-1,470**	**-1,516**	**-1,553**	**-1,578**	**-1,509**	**-1,473**	**-1,411**
5A1	Forest-Land remaining Forest-Land	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5A2	Land converted to Forest-Land	Gg CO2	-1,174	-1,238	-1,356	-1,428	-1,488	-1,402	-1,235	-1,067	-992	-836	-1,435	-1,470	-1,516	-1,553	-1,578	-1,509	-1,473	-1,411
5B	**Cropland**	**Gg CO2**	**969**	**978**	**985**	**986**	**993**	**1,000**	**1,006**	**1,008**	**1,012**	**1,016**	**1,021**	**1,024**	**1,029**	**1,035**	**1,038**	**1,040**	**1,045**	**1,050**
5B1	Cropland remaining Cropland	Gg CO2	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11	-11
5B2	Land converted to Cropland	Gg CO2	969	976	982	988	994	1,000	1,005	1,011	1,016	1,020	1,025	1,030	1,034	1,038	1,042	1,046	1,050	1,053
5B (liming)	*Liming of Cropland*	*Gg CO2*	*11*	*13*	*14*	*9*	*10*	*11*	*12*	*9*	*7*	*6*	*7*	*6*	*6*	*8*	*7*	*5*	*6*	*7*
5C	**Grassland**	**Gg CO2**	**-398**	**-388**	**-442**	**-446**	**-447**	**-442**	**-460**	**-461**	**-497**	**-509**	**-530**	**-528**	**-547**	**-545**	**-557**	**-562**	**-575**	**-601**
5C1	Grassland remaining Grassland	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5C2	Land converted to Grassland	Gg CO2	-490	-501	-512	-524	-535	-545	-554	-566	-575	-578	-582	-586	-597	-607	-616	-624	-633	-643
5C (liming)	*Liming of Grassland*	*Gg CO2*	*90*	*112*	*68*	*76*	*86*	*101*	*92*	*103*	*76*	*64*	*44*	*48*	*41*	*53*	*52*	*55*	*51*	*37*
5C2	Biomass loss from deforestation to products	GgCO2	2	2	2	2	2	2	2	2	2	5	8	10	9	8	7	7	7	6
5D	**Wetland**	**Gg CO2**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	Wetland remaining Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**713**	**710**	**707**	**705**	**704**	**701**	**701**	**703**	**702**	**699**	**698**	**698**	**696**	**696**	**695**	**694**	**691**	**692**
5E1	Settlements remaining Settlements	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5E2	Land converted to Settlements	Gg CO2	*708*	*705*	*702*	*701*	*700*	*697*	*697*	*698*	*697*	*694*	*693*	*693*	*691*	*691*	*690*	*689*	*688*	*688*
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	6	5	5	4	5	4	4	5	5	5	5	6	5	5	5	4	4	4
5F	**Other-Land**	**Gg CO2**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
5F1	Other-Land remaining Other-land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-348**	**-256**	**-141**	**-71**	**-16**	**-50**	**-179**	**-295**	**-335**	**-437**	**121**	**148**	**175**	**175**	**170**	**110**	**116**	**68**
5G1	Harvested Wood Products	Gg CO2	-348	-256	-141	-71	-16	-50	-179	-295	-335	-437	121	148	175	175	170	110	116	68
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	18	18	18	18	18	18	19	20	20	23	26	29	28	27	26	26	25	25
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	1,204	1,210	1,219	1,227	1,237	1,243	1,242	1,241	1,246	1,253	1,294	1,310	1,317	1,322	1,329	1,337	1,346	1,351

Wales			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CH4**	**0.051**	**0.067**	**0.039**	**0.043**	**0.041**	**0.138**	**0.082**	**0.099**	**0.073**	**0.050**	**0.080**	**0.096**	**0.081**	**0.081**	**0.077**	**0.052**	**0.051**	**0.067**
5A2	Forest wildfires	Gg CH4	0.017	0.036	0.009	0.016	0.013	0.112	0.053	0.068	0.042	0.006	0.024	0.028	0.022	0.024	0.025	0.001	0.017	0.036
5C2	Land converted to Grassland	Gg CH4	0.008	0.009	0.010	0.007	0.008	0.009	0.010	0.009	0.009	0.022	0.033	0.044	0.038	0.036	0.032	0.032	0.008	0.009
5E2	Land converted to Settlements	Gg CH4	0.025	0.023	0.020	0.019	0.020	0.017	0.019	0.022	0.022	0.022	0.023	0.024	0.021	0.021	0.020	0.019	0.025	0.023
Information Item	Forest Land converted to other Land-Use Categories	Gg CH4	0.034	0.032	0.030	0.027	0.028	0.026	0.030	0.031	0.031	0.044	0.056	0.068	0.059	0.057	0.052	0.052	0.034	0.032
Information Item	Grassland converted to other Land-Use Categories	Gg CH4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg N2O**	**0.0006**	**0.0008**	**0.0005**	**0.0005**	**0.0005**	**0.0011**	**0.0007**	**0.0008**	**0.0007**	**0.0005**	**0.0007**	**0.0008**	**0.0007**	**0.0007**	**0.0007**	**0.0005**	**0.0006**	**0.0008**
5A2	N fertilisation of forests	Gg N2O	0.0003	0.0003	0.0003	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0002	0.0001	0.0001	0.0003	0.0003
5A2	Forest wildfires	Gg N2O	0.0001	0.0002	0.0001	0.0001	0.0001	0.0008	0.0004	0.0005	0.0003	0.0000	0.0002	0.0002	0.0002	0.0002	0.0002	0.0000	0.0001	0.0002
5C2	Land converted to Grassland	Gg N2O	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0003	0.0003	0.0002	0.0002	0.0002	0.0001	0.0001
5E2	Land converted to Settlements	Gg N2O	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0004	0.0005	0.0004	0.0004	0.0004	0.0004	0.0002	0.0002
Information Item	Grassland converted to other Land-Use Categories	Gg N2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg NOx**	**0.013**	**0.017**	**0.010**	**0.011**	**0.010**	**0.034**	**0.020**	**0.025**	**0.018**	**0.012**	**0.020**	**0.024**	**0.020**	**0.020**	**0.019**	**0.013**	**0.013**	**0.017**
5A2	Forest wildfires	Gg NOx	0.004	0.009	0.002	0.004	0.003	0.028	0.013	0.017	0.010	0.002	0.006	0.007	0.006	0.006	0.006	0.000	0.004	0.009
5C2	Land converted to Grassland	Gg NOx	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.006	0.008	0.011	0.010	0.009	0.008	0.008	0.002	0.002
5E2	Land converted to Settlements	Gg NOx	0.006	0.006	0.005	0.005	0.005	0.004	0.005	0.006	0.005	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.006	0.006
Information Item	Forest Land converted to other Land-Use Categories	Gg NOx	0.008	0.008	0.007	0.007	0.007	0.006	0.007	0.008	0.008	0.011	0.014	0.017	0.015	0.014	0.013	0.013	0.008	0.008
Information Item	Grassland converted to other Land-Use Categories	Gg NOx	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg CO**	**0.446**	**0.590**	**0.343**	**0.375**	**0.356**	**1.208**	**0.722**	**0.863**	**0.639**	**0.439**	**0.696**	**0.837**	**0.709**	**0.713**	**0.676**	**0.459**	**0.446**	**0.590**
5A2	Forest wildfires	Gg CO	0.152	0.312	0.079	0.140	0.114	0.984	0.463	0.592	0.368	0.054	0.206	0.241	0.195	0.210	0.218	0.008	0.152	0.312
5C2	Land converted to Grassland	Gg CO	0.073	0.078	0.085	0.065	0.069	0.077	0.091	0.075	0.079	0.195	0.293	0.385	0.335	0.315	0.281	0.283	0.073	0.078
5E2	Land converted to Settlements	Gg CO	0.221	0.200	0.179	0.170	0.172	0.146	0.168	0.195	0.192	0.190	0.197	0.210	0.180	0.187	0.177	0.168	0.221	0.200
Information Item	Forest Land converted to other Land-Use Categories	Gg CO	0.294	0.278	0.264	0.235	0.241	0.223	0.259	0.271	0.271	0.385	0.490	0.596	0.515	0.503	0.458	0.451	0.294	0.278
Information Item	Grassland converted to other Land-Use Categories	Gg CO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table A3. 5 : N. Ireland

N. Ireland			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CO2**	**-30**	**-36**	**-111**	**-121**	**-135**	**-141**	**-163**	**-172**	**-220**	**-244**	**-274**	**-274**	**-291**	**-290**	**-282**	**-282**	**-295**	**-286**
5A	Forest Land	Gg CO2	**-730**	**-732**	**-759**	**-713**	**-747**	**-720**	**-706**	**-702**	**-705**	**-714**	**-731**	**-746**	**-727**	**-695**	**-688**	**-633**	**-622**	**-543**
5A1	Forest-Land remaining Forest-Land	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5A2	Land converted to Forest-Land	Gg CO2	-730	-732	-759	-713	-747	-720	-706	-702	-705	-714	-731	-746	-727	-695	-688	-633	-622	-543
5B	**Cropland**	**Gg CO2**	**1,255**	**1,244**	**1,232**	**1,216**	**1,205**	**1,196**	**1,187**	**1,175**	**1,165**	**1,156**	**1,149**	**1,142**	**1,135**	**1,130**	**1,124**	**1,117**	**1,113**	**1,108**
5B1	Cropland remaining Cropland	Gg CO2	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25	-25
5B2	Land converted to Cropland	Gg CO2	1,271	1,257	1,245	1,233	1,222	1,212	1,202	1,193	1,184	1,176	1,169	1,162	1,155	1,149	1,144	1,138	1,133	1,128
5B (liming)	*Liming of Cropland*	*Gg CO2*	*9*	*12*	*12*	*8*	*8*	*10*	*10*	*7*	*6*	*5*	*5*	*5*	*5*	*6*	*5*	*4*	*5*	*5*
5C	**Grassland**	**Gg CO2**	**-1,079**	**-1,071**	**-1,116**	**-1,118**	**-1,118**	**-1,113**	**-1,130**	**-1,129**	**-1,160**	**-1,178**	**-1,201**	**-1,204**	**-1,216**	**-1,215**	**-1,222**	**-1,229**	**-1,239**	**-1,254**
5C1	Grassland remaining Grassland	Gg CO2	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102
5C2	Land converted to Grassland	Gg CO2	-1,254	-1,263	-1,273	-1,282	-1,290	-1,299	-1,307	-1,315	-1,323	-1,330	-1,338	-1,345	-1,352	-1,359	-1,365	-1,372	-1,378	-1,384
5C (liming)	*Liming of Grassland*	*Gg CO2*	*73*	*91*	*55*	*62*	*70*	*84*	*76*	*84*	*62*	*51*	*35*	*40*	*35*	*42*	*42*	*41*	*38*	*28*
5C2	Biomass loss from deforestation to products	*GgCO2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5D	**Wetland**	**Gg CO2**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**	**IE**
5D1	Wetland remaining Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**570**	**569**	**569**	**569**	**569**	**568**	**568**	**568**	**568**	**568**	**568**	**569**	**569**	**569**	**569**	**569**	**569**	**569**
5E1	Settlements remaining Settlements	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5E2	Land converted to Settlements	Gg CO2	*570*	*569*	*569*	*569*	*569*	*568*	*568*	*568*	*568*	*568*	*568*	*569*	*569*	*569*	*569*	*569*	*569*	*569*
5E (Biomass burning)	*Forest Land converted to Settlement*	Gg CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5F	**Other-Land**	**Gg CO2**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
5F1	Other-Land remaining Other-land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-45**	**-46**	**-37**	**-74**	**-43**	**-72**	**-82**	**-84**	**-89**	**-77**	**-60**	**-35**	**-53**	**-80**	**-65**	**-107**	**-116**	**-166**
5G1	Harvested Wood Products	Gg CO2	-45	-46	-37	-74	-43	-72	-82	-84	-89	-77	-60	-35	-53	-80	-65	-107	-116	-166
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	63	59	56	53	50	47	45	42	40	38	36	34	32	31	29	28	26	25
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	1,688	1,685	1,674	1,664	1,659	1,648	1,635	1,623	1,610	1,599	1,591	1,585	1,576	1,568	1,560	1,549	1,542	1,537

N. Ireland			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
5	**Total Land-Use Categories**	**Gg CH4**	**0.059**	**0.042**	**0.011**	**0.018**	**0.012**	**0.008**	**0.050**	**0.073**	**0.012**	**0.005**	**0.003**	**0.050**	**0.052**	**0.001**	**0.058**	**0.049**	**0.002**	**0.037**
5A2	Forest wildfires	Gg CH4	0.059	0.042	0.011	0.018	0.012	0.008	0.050	0.073	0.012	0.005	0.003	0.050	0.052	0.001	0.058	0.049	0.002	0.037
5C2	Land converted to Grassland	Gg CH4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5E2	Land converted to Settlements	Gg CH4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Information Item	Forest Land converted to other Land-Use Categories	Gg CH4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33
Information Item	Grassland converted to other Land-Use Categories	Gg CH4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg N2O**	**0.0008**	**0.0006**	**0.0003**	**0.0006**	**0.0004**	**0.0003**	**0.0007**	**0.0008**	**0.0002**	**0.0002**	**0.0002**	**0.0005**	**0.0005**	**0.0001**	**0.0005**	**0.0004**	**0.0001**	**0.0003**
5A2	N fertilisation of forests	Gg N2O	0.0004	0.0003	0.0003	0.0005	0.0004	0.0002	0.0003	0.0003	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000
5A2	Forest wildfires	Gg N2O	0.0004	0.0003	0.0001	0.0001	0.0001	0.0001	0.0003	0.0005	0.0001	0.0000	0.0000	0.0003	0.0004	0.0000	0.0004	0.0003	0.0000	0.0003
5C2	Land converted to Grassland	Gg N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5E2	Land converted to Settlements	Gg N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Information Item	Grassland converted to other Land-Use Categories	Gg N2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg NOx**	**0.015**	**0.010**	**0.003**	**0.005**	**0.003**	**0.002**	**0.012**	**0.018**	**0.003**	**0.001**	**0.001**	**0.013**	**0.013**	**0.000**	**0.014**	**0.012**	**0.015**	**0.010**
5A2	Forest wildfires	Gg NOx	0.015	0.010	0.003	0.005	0.003	0.002	0.012	0.018	0.003	0.001	0.001	0.013	0.013	0.000	0.014	0.012	0.015	0.010
5C2	Land converted to Grassland	Gg NOx	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5E2	Land converted to Settlements	Gg NOx	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Information Item	Forest Land converted to other Land-Use Categories	Gg NOx	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Information Item	Grassland converted to other Land-Use Categories	Gg NOx	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total Land-Use Categories**	**Gg CO**	**0.521**	**0.370**	**0.093**	**0.161**	**0.107**	**0.073**	**0.435**	**0.636**	**0.106**	**0.044**	**0.030**	**0.441**	**0.455**	**0.006**	**0.507**	**0.431**	**0.521**	**0.370**
5A2	Forest wildfires	Gg CO	0.521	0.370	0.093	0.161	0.107	0.073	0.435	0.636	0.106	0.044	0.030	0.441	0.455	0.006	0.507	0.431	0.521	0.370
5C2	Land converted to Grassland	Gg CO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5E2	Land converted to Settlements	Gg CO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Information Item	Forest Land converted to other Land-Use Categories	Gg CO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Information Item	Grassland converted to other Land-Use Categories	Gg CO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

24.4 Appendix 4: Removals and Emissions by activities under Article 3.3 and 3.4 of the Kyoto Protocol

PLEASE NOTE

- These tables have been updated from the format used in previous years to better reflect the CRF Kyoto Protocol reporting tables now provided by the UNFCCC. Some columns contain notation keys where the activity does not occur in the UK (NO) or the activity is not currently estimated (NE). IE means included elsewhere, and is used for wildfire emissions on Art 3.3 Afforestation land – all wildfires in forests are currently reported under Forest Management.

- Post-2006 Afforestation fluxes are from forests planted 1990-2006 only (not including projected planting).
- The Deforestation estimates have been updated to reflect the fact that when deforestation occurs 60% is removed as wood products (reported as an immediate emission from the Biomass sector as HWP are not reported under the Kyoto Protocol) and 40% are burnt. The UNFCCC inventory will be amended in the next submission to make this linkage clearer.
- If you require updated projection estimates (Hi, Mid, Low scenarios) to 2020 please contact Amanda Thomson – there has not been time to include them at the time of writing this report.
- Please remember that carbon credits from Article 3.4 Forest Management are capped during the first commitment period (2008-2012) at 1.36 $MtCO_2$ per year.

Table A4. 1: Removals and emissions of greenhouse gases by Article 3.3 Afforestation– United Kingdom 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Liming**	**Biomass burning**	**Biomass burning**	**Fertilisation**	**Drainage**	**Biomass burning**	
1990	-140.9	138.3	NO	IE	IE	0.0207	NE	IE	3.8
1991	-270.8	358.2	NO	IE	IE	0.0218	NE	IE	94.2
1992	-430.7	511.5	NO	IE	IE	0.0209	NE	IE	87.3
1993	-631.2	619.6	NO	IE	IE	0.0143	NE	IE	-7.1
1994	-890.7	698.0	NO	IE	IE	0.0127	NE	IE	-188.7
1995	-1166.7	750.0	NO	IE	IE	0.0126	NE	IE	-412.7
1996	-1438.9	771.2	NO	IE	IE	0.0107	NE	IE	-664.4
1997	-1682.6	774.8	NO	IE	IE	0.0099	NE	IE	-904.7
1998	-1890.3	762.1	NO	IE	IE	0.0103	NE	IE	-1125.0
1999	-2065.8	741.8	NO	IE	IE	0.0089	NE	IE	-1321.3
2000	-2213.2	723.6	NO	IE	IE	0.0091	NE	IE	-1486.8
2001	-2323.9	676.0	NO	IE	IE	0.0079	NE	IE	-1645.4
2002	-2415.9	587.2	NO	IE	IE	0.0071	NE	IE	-1826.5
2003	-2494.0	480.2	NO	IE	IE	0.0071	NE	IE	-2011.6
2004	-2557.8	370.2	NO	IE	IE	0.0060	NE	IE	-2185.8
2005	-2596.4	248.8	NO	IE	IE	0.0051	NE	IE	-2346.0
2006	-2629.8	124.2	NO	IE	IE	0.0043	NE	IE	-2504.3
2007	-2644.6	3.0	NO	IE	IE	0.0037	NE	IE	-2640.5
2008	*-2622.7*	*-163.1*	*NO*	*IE*	*IE*	*0.0036*	*NE*	*IE*	*-2784.8*
2009	*-2597.2*	*-347.1*	*NO*	*IE*	*IE*	*0.0027*	*NE*	*IE*	*-2943.4*
2010	*-2601.2*	*-495.9*	*NO*	*IE*	*IE*	*0.0027*	*NE*	*IE*	*-3096.2*
2011	*-2581.4*	*-615.3*	*NO*	*IE*	*IE*	*0.0027*	*NE*	*IE*	*-3195.8*
2012	*-2541.2*	*-710.2*	*NO*	*IE*	*IE*	*0.0027*	*NE*	*IE*	*-3250.5*

Table A4. 2: Removals and emissions of greenhouse gases by Article 3.3 Deforestation- United Kingdom 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**		**Net CO_2 eq. flux**
	Biomass	**Soils**	**Liming**	**Biomass burning**	**Biomass burning**	**Deforestation to cropland**	**Biomass burning**	
1990	226.1	17.5	NO	135.654	0.592	NE	0.004	392.9
1991	213.4	33.9	NO	128.043	0.559	NE	0.004	388.3
1992	202.9	49.4	NO	121.717	0.531	NE	0.004	386.3
1993	180.5	64.0	NO	108.324	0.473	NE	0.003	363.8
1994	185.4	77.7	NO	111.248	0.485	NE	0.003	385.6
1995	171.6	90.7	NO	102.941	0.449	NE	0.003	375.6
1996	198.9	102.9	NO	119.365	0.521	NE	0.004	433.3
1997	207.9	114.4	NO	124.761	0.544	NE	0.004	459.7
1998	208.1	125.3	NO	124.849	0.545	NE	0.004	470.8
1999	296.0	135.6	NO	177.622	0.775	NE	0.005	627.1
2000	376.4	145.3	NO	225.832	0.985	NE	0.007	770.3
2001	457.7	154.4	NO	274.611	1.198	NE	0.008	914.4
2002	395.5	163.1	NO	237.306	1.036	NE	0.007	819.8
2003	386.3	171.3	NO	231.769	1.011	NE	0.007	812.7
2004	352.1	179.0	NO	211.290	0.922	NE	0.006	763.8
2005	346.5	186.3	NO	207.923	0.907	NE	0.006	761.8
2006	305.8	193.2	NO	183.478	0.801	NE	0.006	701.0
2007	282.4	199.8	NO	169.432	0.739	NE	0.005	668.7
2008	*256.8*	*206.0*	*NO*	*154.052*	*0.672*	*NE*	*0.005*	*632.3*
2009	*260.2*	*211.8*	*NO*	*156.139*	*0.681*	*NE*	*0.005*	*644.0*
2010	*273.0*	*217.4*	*NO*	*163.826*	*0.715*	*NE*	*0.005*	*670.8*
2011	*264.5*	*222.6*	*NO*	*158.705*	*0.693*	*NE*	*0.005*	*661.9*
2012	*252.8*	*227.6*	*NO*	*151.653*	*0.662*	*NE*	*0.005*	*647.3*

Table A4. 3: Article 3.3 ARD emissions and removals – UK 1990-2012

Year	**Afforestation**			**Deforestation**			
	Net CO_2 emissions/ removals Gg	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 emissions/ removals Gg**	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 eq. emissions/ removals Gg**
1990	-2.6	IE	0.0207	379.3	0.592	0.004	396.7
1991	87.4	IE	0.0218	375.3	0.559	0.004	463.3
1992	80.8	IE	0.0209	374.0	0.531	0.004	455.4
1993	-11.6	IE	0.0143	352.8	0.473	0.003	341.7
1994	-192.7	IE	0.0127	374.3	0.485	0.003	182.1
1995	-416.7	IE	0.0126	365.2	0.449	0.003	-51.0
1996	-667.7	IE	0.0107	421.2	0.521	0.004	-246.0
1997	-907.8	IE	0.0099	447.1	0.544	0.004	-460.2
1998	-1128.2	IE	0.0103	458.2	0.545	0.004	-669.4
1999	-1324	IE	0.0089	609.2	0.775	0.005	-714.0
2000	-1489.6	IE	0.0091	747.5	0.985	0.007	-741.1
2001	-1647.9	IE	0.0079	886.7	1.198	0.008	-760.0
2002	-1828.7	IE	0.0071	795.9	1.036	0.007	-1031.7
2003	-2013.8	IE	0.0071	789.4	1.011	0.007	-1223.4
2004	-2187.6	IE	0.006	742.4	0.922	0.006	-1444.3
2005	-2347.6	IE	0.0051	740.7	0.907	0.006	-1606.0
2006	-2505.6	IE	0.0043	682.5	0.801	0.006	-1822.3
2007	-2641.6	IE	0.0037	651.6	0.739	0.005	-1989.2
2008	*-2785.8*	*IE*	*0.0036*	*616.9*	*0.672*	*0.005*	*-2168.3*
2009	*-2944.3*	*IE*	*0.0027*	*628.1*	*0.681*	*0.005*	*-2315.5*
2010	*-3097.1*	*IE*	*0.0027*	*654.2*	*0.715*	*0.005*	*-2442.2*
2011	*-3196.7*	*IE*	*0.0027*	*645.8*	*0.693*	*0.005*	*-2550.2*
2012	*-3251.4*	*IE*	*0.0027*	*632.1*	*0.662*	*0.005*	*-2618.7*

Table A4. 4: Removal and emissions of greenhouse gases by Article 3.4 Forest Management- UK 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Fertilis-ation**	**Drain-age**	**Biomass burning**	
1990	-10513.7	-1717.3	NO	46.902	0.205	NE	NE	0.001	-12179.4
1991	-10756.6	-2134.6	NO	79.091	0.345	NE	NE	0.002	-12804.1
1992	-11088.4	-2459.9	NO	20.041	0.087	NE	NE	0.001	-13526.2
1993	-11123.0	-2716.5	NO	35.224	0.154	NE	NE	0.001	-13800.7
1994	-11243.4	-2904.8	NO	28.050	0.122	NE	NE	0.001	-14117.3
1995	-10617.2	-3053.2	NO	219.402	0.957	NE	NE	0.007	-13428.8
1996	-10031.6	-3166.0	NO	114.047	0.498	NE	NE	0.003	-13072.0
1997	-9474.5	-3253.0	NO	149.745	0.653	NE	NE	0.004	-12562.6
1998	-9088.9	-3303.5	NO	82.964	0.362	NE	NE	0.002	-12301.1
1999	-8959.0	-3318.1	NO	13.097	0.057	NE	NE	0.000	-12262.7
2000	-9100.9	-3282.2	NO	45.767	0.200	NE	NE	0.001	-12332.7
2001	-9524.0	-3237.7	NO	63.248	0.276	NE	NE	0.002	-12692.1
2002	-10108.2	-3185.5	NO	53.535	0.234	NE	NE	0.002	-13234.8
2003	-10561.4	-3130.8	NO	45.206	0.197	NE	NE	0.001	-13642.4
2004	-11086.6	-3067.1	NO	59.816	0.261	NE	NE	0.002	-14087.8
2005	-10385.4	-3020.3	NO	23.621	0.103	NE	NE	0.0007	-13379.7
2006	-9743.7	-2994.3	NO	131.2688	0.5728	NE	NE	0.0039	-12593.5
2007	-8707.3	-2976.1	NO	158.5997	0.6921	NE	NE	0.0048	-11508.8
2008	*-8059.7*	*-2937.9*	*NO*	*149.5101*	*0.6524*	*NE*	*NE*	*0.0045*	*-10833.0*
2009	*-7114.5*	*-2892.4*	*NO*	*83.3081*	*0.3635*	*NE*	*NE*	*0.0025*	*-9915.2*
2010	*-4801.0*	*-2867.2*	*NO*	*78.7944*	*0.3438*	*NE*	*NE*	*0.0024*	*-7581.5*
2011	*-4654.1*	*-2776.9*	*NO*	*34.5892*	*0.1509*	*NE*	*NE*	*0.0010*	*-7392.9*
2012	*-3806.0*	*-2701.6*	*NO*	*70.0916*	*0.3059*	*NE*	*NE*	*0.0021*	*-6430.4*

Table A4. 5: Removals and emissions of greenhouse gases by Article 3.3 Afforestation– England 1990-2012

Year	**CO$_2$ emissions/removals Gg**				**CH$_4$ emissions Gg**	**N$_2$O emissions Gg**			**Net CO$_2$ eq. flux**
	Biomass	**Soils**	**Liming**	**Biomass burning**	**Biomass burning**	**Fertilisation**	**Drainage**	**Biomass burning**	
1990	-41.8	31.3	NO	IE	IE	0.0018	NE	IE	-9.9
1991	-81.4	80.7	NO	IE	IE	0.0017	NE	IE	-0.1
1992	-134.6	116.6	NO	IE	IE	0.0025	NE	IE	-17.3
1993	-206.9	146.4	NO	IE	IE	0.0030	NE	IE	-59.6
1994	-297.7	167.3	NO	IE	IE	0.0026	NE	IE	-129.5
1995	-388.9	166.3	NO	IE	IE	0.0027	NE	IE	-221.7
1996	-481.0	149.3	NO	IE	IE	0.0029	NE	IE	-330.8
1997	-560.5	127.8	NO	IE	IE	0.0026	NE	IE	-431.9
1998	-627.5	106.6	NO	IE	IE	0.0026	NE	IE	-520.0
1999	-674.0	86.7	NO	IE	IE	0.0028	NE	IE	-586.5
2000	-706.5	65.8	NO	IE	IE	0.0027	NE	IE	-639.9
2001	-726.6	42.3	NO	IE	IE	0.0028	NE	IE	-683.5
2002	-744.9	16.8	NO	IE	IE	0.0030	NE	IE	-727.2
2003	-759.2	-9.8	NO	IE	IE	0.0027	NE	IE	-768.2
2004	-773.8	-36.3	NO	IE	IE	0.0027	NE	IE	-809.3
2005	-784.1	-64.5	NO	IE	IE	0.0023	NE	IE	-847.8
2006	-800.3	-89.7	NO	IE	IE	0.0018	NE	IE	-889.5
2007	-810.9	-114.6	NO	IE	IE	0.0020	NE	IE	-924.9
2008	*-809.6*	*-155.9*	*NO*	*IE*	*IE*	*0.0016*	*NE*	*IE*	*-965.0*
2009	*-808.3*	*-202.9*	*NO*	*IE*	*IE*	*0.0014*	*NE*	*IE*	*-1010.8*
2010	*-812.5*	*-241.1*	*NO*	*IE*	*IE*	*0.0014*	*NE*	*IE*	*-1053.1*
2011	*-807.3*	*-271.7*	*NO*	*IE*	*IE*	*0.0014*	*NE*	*IE*	*-1078.6*
2012	*-794.0*	*-296.1*	*NO*	*IE*	*IE*	*0.0014*	*NE*	*IE*	*-1089.6*

Table A4. 6: Removals and emissions of greenhouse gases by Article 3.3 Deforestation– England 1990-2012

Year	**CO$_2$ emissions/removals Gg**				**CH$_4$ emissions Gg**	**N$_2$O emissions Gg**		**Net CO$_2$ eq. flux**
	Biomass	**Soils**	**Liming**	**Biomass burning**	**Biomass burning**	**Deforestation to cropland**	**Biomass burning**	
1990	162.4	12.5	NO	97.4248	0.4251	NE	0.0029	282.2
1991	153.3	24.4	NO	91.9591	0.4013	NE	0.0028	278.9
1992	145.7	35.5	NO	87.4153	0.3814	NE	0.0026	277.4
1993	129.7	46.0	NO	77.7970	0.3395	NE	0.0023	261.3
1994	133.2	55.8	NO	79.8970	0.3486	NE	0.0024	276.9
1995	123.2	65.1	NO	73.9306	0.3226	NE	0.0022	269.7
1996	142.9	73.9	NO	85.7261	0.3741	NE	0.0026	311.2
1997	149.3	82.2	NO	89.6016	0.3910	NE	0.0027	330.2
1998	149.4	90.0	NO	89.6650	0.3913	NE	0.0027	338.1
1999	212.6	97.4	NO	127.5661	0.5567	NE	0.0038	450.4
2000	270.3	104.3	NO	162.1892	0.7077	NE	0.0049	553.2
2001	328.7	110.9	NO	197.2218	0.8606	NE	0.0059	656.7
2002	284.0	117.1	NO	170.4298	0.7437	NE	0.0051	588.8
2003	277.4	123.0	NO	166.4533	0.7263	NE	0.0050	583.7
2004	252.9	128.6	NO	151.7454	0.6622	NE	0.0046	548.5
2005	248.9	133.8	NO	149.3277	0.6516	NE	0.0045	547.1
2006	219.6	138.8	NO	131.7716	0.5750	NE	0.0040	503.5
2007	202.8	143.5	NO	121.6836	0.5310	NE	0.0037	480.3
2008	*184.4*	*147.9*	*NO*	*110.6378*	*0.4828*	*NE*	*0.0033*	*454.1*
2009	*186.9*	*152.1*	*NO*	*112.1371*	*0.4893*	*NE*	*0.0034*	*462.5*
2010	*196.1*	*156.1*	*NO*	*117.6575*	*0.5134*	*NE*	*0.0035*	*481.8*
2011	*190.0*	*159.9*	*NO*	*113.9796*	*0.4974*	*NE*	*0.0034*	*475.3*
2012	*181.5*	*163.5*	*NO*	*108.9148*	*0.4753*	*NE*	*0.0033*	*464.9*

Table A4. 7: Article 3.3 ARD emissions and removals – England 1990-2012

Year	**Afforestation**			**Deforestation**			
	Net CO_2 emissions/ removals Gg	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 emissions/ removals Gg**	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 eq. emissions/ removals Gg**
1990	-10.5	IE	0.0018	272.3	0.4251	0.0029	272.2
1991	-0.7	IE	0.0017	269.7	0.4013	0.0028	269.4
1992	-18.0	IE	0.0025	268.6	0.3814	0.0026	251.0
1993	-60.5	IE	0.0030	253.5	0.3395	0.0023	193.3
1994	-130.4	IE	0.0026	268.9	0.3486	0.0024	138.9
1995	-222.6	IE	0.0027	262.2	0.3226	0.0022	40.0
1996	-331.7	IE	0.0029	302.5	0.3741	0.0026	-28.8
1997	-432.7	IE	0.0026	321.1	0.3910	0.0027	-111.2
1998	-520.9	IE	0.0026	329.1	0.3913	0.0027	-191.4
1999	-587.3	IE	0.0028	437.6	0.5567	0.0038	-149.2
2000	-640.7	IE	0.0027	536.8	0.7077	0.0049	-103.2
2001	-684.3	IE	0.0028	636.8	0.8606	0.0059	-46.6
2002	-728.1	IE	0.0030	571.5	0.7437	0.0051	-155.8
2003	-769.0	IE	0.0027	566.9	0.7263	0.0050	-201.4
2004	-810.1	IE	0.0027	533.2	0.6622	0.0046	-276.2
2005	-848.6	IE	0.0023	532.0	0.6516	0.0045	-315.9
2006	-890.0	IE	0.0018	490.2	0.5750	0.0040	-399.2
2007	-925.5	IE	0.0020	468.0	0.5310	0.0037	-457.0
2008	*-965.5*	*IE*	*0.0016*	*442.9*	*0.4828*	*0.0033*	*-522.1*
2009	*-1011.2*	*IE*	*0.0014*	*451.1*	*0.4893*	*0.0034*	*-559.6*
2010	*-1053.6*	*IE*	*0.0014*	*469.9*	*0.5134*	*0.0035*	*-583.2*
2011	*-1079.0*	*IE*	*0.0014*	*463.9*	*0.4974*	*0.0034*	*-614.6*
2012	*-1090.1*	*IE*	*0.0014*	*453.9*	*0.4753*	*0.0033*	*-635.7*

Table A4. 8: Removal and emissions of greenhouse gases by Article 3.4 Forest Management- England 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Fertilis-ation**	**Drain-age**	**Biomass burning**	
1990	-1847.1	-882.6	NO	16.711	0.073	NE	NE	0.001	-2711.4
1991	-1898.6	-879.7	NO	34.511	0.151	NE	NE	0.001	-2740.3
1992	-1976.6	-876.7	NO	8.670	0.038	NE	NE	0.000	-2843. 8
1993	-1948.8	-873.6	NO	15.102	0.066	NE	NE	0.000	-2805.7
1994	-1953.3	-866.6	NO	12.135	0.053	NE	NE	0.000	-2806.5
1995	-1842.3	-859.1	NO	103.413	0.451	NE	NE	0.003	-2587.6
1996	-1850.8	-848.5	NO	48.336	0.211	NE	NE	0.001	-2646.1
1997	-1759.7	-840.8	NO	62.158	0.271	NE	NE	0.002	-2532.0
1998	-1641.8	-831.9	NO	37.250	0.163	NE	NE	0.001	-2432.6
1999	-1646.6	-816.6	NO	5.490	0.024	NE	NE	0.000	-2457.2
2000	-1492.4	-801.9	NO	20.393	0.089	NE	NE	0.001	-2271.9
2001	-1654.4	-778.8	NO	23.192	0.101	NE	NE	0.001	-2407.6
2002	-1855.5	-753.3	NO	18.467	0.081	NE	NE	0.001	-2588.5
2003	-1990.3	-730.4	NO	19.803	0.086	NE	NE	0.001	-2699.0
2004	-2168.2	-708.0	NO	20.296	0.089	NE	NE	0.001	-2853.8
2005	-2033.3	-692.7	NO	9.215	0.040	NE	NE	0.000	-2715.9
2006	-1857.7	-685.3	NO	50.938	0.222	NE	NE	0.002	-2487.0
2007	-1461.5	-685.6	NO	60.994	0.266	NE	NE	0.002	-2080.0
2008	*-1184.2*	*-679.3*	*NO*	*58.144*	*0.254*	*NE*	*NE*	*0.002*	*-1799.5*
2009	*-887.4*	*-671.9*	*NO*	*28.295*	*0.123*	*NE*	*NE*	*0.001*	*-1528.2*
2010	*-625.9*	*-654.4*	*NO*	*30.461*	*0.133*	*NE*	*NE*	*0.001*	*-1246.8*
2011	*-725.5*	*-625.6*	*NO*	*12.930*	*0.056*	*NE*	*NE*	*0.000*	*-1336.9*
2012	*-499.2*	*-609.2*	*NO*	*24.404*	*0.106*	*NE*	*NE*	*0.001*	*-1081.6*

Table A4. 9: Removals and emissions of greenhouse gases by Article 3.3 Afforestation– Scotland 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Liming**	**Biomass burning**	**Biomass burning**	**Fertilisation**	**Drainage**	**Biomass burning**	
1990	-57.1	75.6	NO	IE	IE	0.0194	NE	IE	24.5
1991	-110.2	198.1	NO	IE	IE	0.0187	NE	IE	93.7
1992	-172.8	284.7	NO	IE	IE	0.0112	NE	IE	115.4
1993	-249.0	344.3	NO	IE	IE	0.0091	NE	IE	98.2
1994	-351.3	391.9	NO	IE	IE	0.0097	NE	IE	43.6
1995	-473.7	448.4	NO	IE	IE	0.0075	NE	IE	-23.0
1996	-592.0	498.2	NO	IE	IE	0.0065	NE	IE	-91.8
1997	-711.0	538.4	NO	IE	IE	0.0074	NE	IE	-170.4
1998	-815.2	562.4	NO	IE	IE	0.0059	NE	IE	-250.9
1999	-921.8	575.2	NO	IE	IE	0.0060	NE	IE	-344.7
2000	-1018.4	590.2	NO	IE	IE	0.0050	NE	IE	-426.6
2001	-1100.8	580.0	NO	IE	IE	0.0041	NE	IE	-519.5
2002	-1169.3	535.3	NO	IE	IE	0.0039	NE	IE	-632.7
2003	-1225.2	472.5	NO	IE	IE	0.0031	NE	IE	-751.8
2004	-1270.0	407.8	NO	IE	IE	0.0023	NE	IE	-861.5
2005	-1292.9	333.9	NO	IE	IE	0.0018	NE	IE	-958.4
2006	-1301.2	249.7	NO	IE	IE	0.0020	NE	IE	-1050.8
2007	-1298.4	168.1	NO	IE	IE	0.0017	NE	IE	-1129.8
2008	*-1274.6*	*68.0*	*NO*	*IE*	*IE*	*0.0013*	*NE*	*IE*	*-1206.2*
2009	*-1246.7*	*-39.4*	*NO*	*IE*	*IE*	*0.0017*	*NE*	*IE*	*-1285.7*
2010	*-1231.8*	*-126.5*	*NO*	*IE*	*IE*	*0.0017*	*NE*	*IE*	*-1357.8*
2011	*-1208.8*	*-196.5*	*NO*	*IE*	*IE*	*0.0017*	*NE*	*IE*	*-1404.9*
2012	*-1181.2*	*-252.5*	*NO*	*IE*	*IE*	*0.0017*	*NE*	*IE*	*-1433.1*

Table A4. 10: Removals and emissions of greenhouse gases by Article 3.3 Deforestation– Scotland 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**		**Net CO_2 eq. flux**
	Biomass	**Soils**	**Liming**	**Biomass burning**	**Biomass burning**	**Deforestation to cropland**	**Biomass burning**	
1990	50.9	3.9	NO	30.5229	0.1332	NE	0.0009	88.4
1991	48.0	7.6	NO	28.8105	0.1257	NE	0.0009	87.4
1992	45.6	11.1	NO	27.3870	0.1195	NE	0.0008	86.9
1993	40.6	14.4	NO	24.3736	0.1064	NE	0.0007	81.9
1994	41.7	17.5	NO	25.0315	0.1092	NE	0.0008	86.8
1995	38.6	20.4	NO	23.1622	0.1011	NE	0.0007	84.5
1996	44.8	23.2	NO	26.8577	0.1172	NE	0.0008	97.5
1997	46.8	25.7	NO	28.0719	0.1225	NE	0.0008	103.4
1998	46.8	28.2	NO	28.0918	0.1226	NE	0.0008	105.9
1999	66.6	30.5	NO	39.9661	0.1744	NE	0.0012	141.1
2000	84.7	32.7	NO	50.8134	0.2217	NE	0.0015	173.3
2001	103.0	34.7	NO	61.7890	0.2696	NE	0.0019	205.8
2002	89.0	36.7	NO	53.3952	0.2330	NE	0.0016	184.5
2003	86.9	38.5	NO	52.1493	0.2276	NE	0.0016	182.9
2004	79.2	40.3	NO	47.5414	0.2075	NE	0.0014	171.9
2005	78.0	41.9	NO	46.7839	0.2041	NE	0.0014	171.4
2006	68.8	43.5	NO	41.2837	0.1801	NE	0.0012	157.7
2007	63.5	45.0	NO	38.1231	0.1664	NE	0.0011	150.5
2008	*57.8*	*46.3*	*NO*	*34.6625*	*0.1513*	*NE*	*0.0010*	*142.3*
2009	*58.6*	*47.7*	*NO*	*35.1323*	*0.1533*	*NE*	*0.0011*	*144.9*
2010	*61.4*	*48.9*	*NO*	*36.8618*	*0.1609*	*NE*	*0.0011*	*150.9*
2011	*59.5*	*50.1*	*NO*	*35.7095*	*0.1558*	*NE*	*0.0011*	*148.9*
2012	*56.9*	*51.2*	*NO*	*34.1227*	*0.1489*	*NE*	*0.0010*	*145.7*

Table A4. 11: Article 3.3 ARD emissions and removals – Scotland 1990-2012

Year	**Afforestation**			**Deforestation**			
	Net CO_2 emissions/ removals Gg	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 emissions/ removals Gg**	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 eq. emissions/ removals Gg**
1990	18.5	IE	0.0194	85.3229	0.1332	0.0009	112.9
1991	87.9	IE	0.0187	84.4105	0.1257	0.0009	172.5
1992	111.9	IE	0.0112	84.0870	0.1195	0.0008	196.1
1993	95.3	IE	0.0091	79.3736	0.1064	0.0007	174.8
1994	40.6	IE	0.0097	84.2315	0.1092	0.0008	125.0
1995	-25.3	IE	0.0075	82.1622	0.1011	0.0007	57.0
1996	-93.8	IE	0.0065	94.8577	0.1172	0.0008	1.2
1997	-172.6	IE	0.0074	100.5719	0.1225	0.0008	-71.9
1998	-252.8	IE	0.0059	103.0918	0.1226	0.0008	-149.6
1999	-346.6	IE	0.0060	137.0661	0.1744	0.0012	-209.4
2000	-428.2	IE	0.0050	168.2134	0.2217	0.0015	-259.8
2001	-520.8	IE	0.0041	199.4890	0.2696	0.0019	-321.0
2002	-634.0	IE	0.0039	179.0952	0.233	0.0016	-454.7
2003	-752.7	IE	0.0031	177.5493	0.2276	0.0016	-574.9
2004	-862.2	IE	0.0023	167.0414	0.2075	0.0014	-694.9
2005	-959.0	IE	0.0018	166.6839	0.2041	0.0014	-792.1
2006	-1051.5	IE	0.0020	153.5837	0.1801	0.0012	-897.7
2007	-1130.3	IE	0.0017	146.6231	0.1664	0.0011	-983.5
2008	*-1206.6*	*IE*	*0.0013*	*138.7625*	*0.1513*	*0.0010*	*-1067.7*
2009	*-1286.1*	*IE*	*0.0017*	*141.4323*	*0.1533*	*0.0011*	*-1144.5*
2010	*-1358.3*	*IE*	*0.0017*	*147.1618*	*0.1609*	*0.0011*	*-1211.0*
2011	*-1405.3*	*IE*	*0.0017*	*145.3095*	*0.1558*	*0.0011*	*-1259.8*
2012	*-1433.7*	*IE*	*0.0017*	*142.2227*	*0.1489*	*0.0010*	*-1291.3*

Table A4. 12: Removal and emissions of greenhouse gases by Article 3.4 Forest Management-Scotland 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Fertilis-ation**	**Drain-age**	**Biomass burning**	
1990	-7279.3	-299.0	NO	12.591	0.055	NE	NE	0.000	-7564.4
1991	-7407.1	-703.4	NO	26.728	0.117	NE	NE	0.001	-8081.1
1992	-7536.1	-1025.5	NO	6.845	0.030	NE	NE	0.000	-8554.0
1993	-7586.0	-1280.4	NO	12.224	0.053	NE	NE	0.000	-8853.0
1994	-7624.8	-1475.5	NO	10.115	0.044	NE	NE	0.000	-9089.2
1995	-7224.8	-1627.8	NO	88.306	0.385	NE	NE	0.003	-8755.4
1996	-6848.6	-1743.0	NO	42.225	0.184	NE	NE	0.001	-8545.1
1997	-6574.5	-1832.6	NO	55.468	0.242	NE	NE	0.002	-8346.0
1998	-6419.2	-1895.4	NO	33.310	0.145	NE	NE	0.001	-8277.9
1999	-6455.4	-1929.5	NO	5.033	0.022	NE	NE	0.000	-8379.4
2000	-6105.2	-1948.9	NO	19.182	0.084	NE	NE	0.001	-8033.1
2001	-6299.2	-1945.1	NO	22.215	0.097	NE	NE	0.001	-8219.8
2002	-6661.5	-1926.7	NO	18.094	0.079	NE	NE	0.001	-8568.3
2003	-6993.8	-1901.6	NO	19.754	0.086	NE	NE	0.001	-8873.7
2004	-7316.0	-1870.2	NO	20.577	0.090	NE	NE	0.001	-9163.5
2005	-6887.3	-1846.0	NO	9.510	0.042	NE	NE	0.000	-8722.9
2006	-6461.9	-1837.1	NO	53.313	0.233	NE	NE	0.002	-8240.3
2007	-5959.0	-1824.2	NO	65.101	0.284	NE	NE	0.002	-7711.5
2008	*-5758.6*	*-1797.4*	*NO*	*63.325*	*0.276*	*NE*	*NE*	*0.002*	*-7486.3*
2009	*-5240.4*	*-1767.9*	*NO*	*31.461*	*0.137*	*NE*	*NE*	*0.001*	*-6973.7*
2010	*-4046.0*	*-1745.7*	*NO*	*34.423*	*0.150*	*NE*	*NE*	*0.001*	*-5753.8*
2011	*-3900.5*	*-1695.2*	*NO*	*14.812*	*0.065*	*NE*	*NE*	*0.000*	*-5579.4*
2012	*-3257.9*	*-1657.1*	*NO*	*28.322*	*0.124*	*NE*	*NE*	*0.001*	*-4883.9*

Table A4. 13: Removals and emissions of greenhouse gases by Article 3.3 Afforestation– Wales 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Fertilis-ation**	**Drainage**	**Biomass burning**	
1990	-34.8	22.7	NO	IE	IE	0.0003	NE	IE	-12.0
1991	-66.5	57.8	NO	IE	IE	0.0003	NE	IE	-8.7
1992	-102.3	79.0	NO	IE	IE	0.0002	NE	IE	-23.3
1993	-143.7	88.4	NO	IE	IE	0.0002	NE	IE	-55.3
1994	-199.2	92.5	NO	IE	IE	0.0001	NE	IE	-106.6
1995	-249.2	87.2	NO	IE	IE	0.0001	NE	IE	-161.9
1996	-298.4	74.8	NO	IE	IE	0.0001	NE	IE	-223.5
1997	-333.6	60.9	NO	IE	IE	0.0001	NE	IE	-272.6
1998	-360.8	46.7	NO	IE	IE	0.0002	NE	IE	-314.1
1999	-375.0	32.6	NO	IE	IE	0.0002	NE	IE	-342.4
2000	-387.5	20.6	NO	IE	IE	0.0001	NE	IE	-366.9
2001	-390.5	8.5	NO	IE	IE	0.0001	NE	IE	-382.0
2002	-391.2	-7.2	NO	IE	IE	0.0002	NE	IE	-398.3
2003	-394.2	-21.2	NO	IE	IE	0.0001	NE	IE	-415.3
2004	-394.6	-35.6	NO	IE	IE	0.0001	NE	IE	-430.1
2005	-395.6	-51.2	NO	IE	IE	0.0001	NE	IE	-446.7
2006	-401.5	-61.6	NO	IE	IE	0.0001	NE	IE	-463.1
2007	-406.1	-69.4	NO	IE	IE	0.0001	NE	IE	-475.5
2008	*-406.6*	*-84.5*	*NO*	*IE*	*IE*	*0.0001*	*NE*	*IE*	*-491.0*
2009	*-408.9*	*-102.9*	*NO*	*IE*	*IE*	*0.0001*	*NE*	*IE*	*-511.7*
2010	*-423.2*	*-117.5*	*NO*	*IE*	*IE*	*0.0001*	*NE*	*IE*	*-540.7*
2011	*-432.6*	*-129.0*	*NO*	*IE*	*IE*	*0.0001*	*NE*	*IE*	*-561.5*
2012	*-436.3*	*-137.8*	*NO*	*IE*	*IE*	*0.0001*	*NE*	*IE*	*-574.1*

Table A4. 14: Removals and emissions of greenhouse gases by Article 3.3 Deforestation– Wales 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**		**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Deforestation to cropland**	**Biomass burning**	
1990	12.8	1.0	NO	7.70617	0.03363	NE	0.00023	22.3
1991	12.1	1.9	NO	7.27384	0.03174	NE	0.00022	22.1
1992	11.5	2.8	NO	6.91444	0.03017	NE	0.00021	21.9
1993	10.3	3.6	NO	6.15364	0.02685	NE	0.00018	20.7
1994	10.5	4.4	NO	6.31974	0.02758	NE	0.00019	21.9
1995	9.7	5.2	NO	5.84781	0.02552	NE	0.00018	21.3
1996	11.3	5.8	NO	6.78082	0.02959	NE	0.00020	24.6
1997	11.8	6.5	NO	7.08737	0.03093	NE	0.00021	26.1
1998	11.8	7.1	NO	7.09238	0.03095	NE	0.00021	26.7
1999	16.8	7.7	NO	10.09031	0.04403	NE	0.00030	35.6
2000	21.4	8.3	NO	12.82895	0.05598	NE	0.00038	43.8
2001	26.0	8.8	NO	15.59998	0.06807	NE	0.00047	51.9
2002	22.5	9.3	NO	13.48077	0.05883	NE	0.00040	46.6
2003	21.9	9.7	NO	13.16623	0.05745	NE	0.00039	46.2
2004	20.0	10.2	NO	12.00286	0.05238	NE	0.00036	43.4
2005	19.7	10.6	NO	11.81162	0.05154	NE	0.00035	43.3
2006	17.4	11.0	NO	10.42296	0.04548	NE	0.00031	39.8
2007	16.0	11.3	NO	9.62501	0.04200	NE	0.00029	38.0
2008	*14.6*	*11.7*	*NO*	*8.75130*	*0.03819*	*NE*	*0.00026*	*35.9*
2009	*14.8*	*12.0*	*NO*	*8.86990*	*0.03871*	*NE*	*0.00027*	*36.6*
2010	*15.5*	*12.3*	*NO*	*9.30655*	*0.04061*	*NE*	*0.00028*	*38.1*
2011	*15.0*	*12.6*	*NO*	*9.01563*	*0.03934*	*NE*	*0.00027*	*37.6*
2012	*14.4*	*12.9*	*NO*	*8.61502*	*0.03759*	*NE*	*0.00026*	*36.8*

Table A4. 15: Article 3.3 ARD emissions and removals – Wales 1990-2012

Year	**Afforestation**			**Deforestation**			
	Net CO_2 emissions/ removals Gg	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 emissions/ removals Gg**	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 eq. emissions/ removals Gg**
1990	-12.1	IE	0.0003	21.5	0.0336	0.0002	10.2
1991	-8.7	IE	0.0003	21.3	0.0317	0.0002	12.6
1992	-23.3	IE	0.0002	21.2	0.0302	0.0002	-2.1
1993	-55.3	IE	0.0002	20.1	0.0269	0.0002	-35.2
1994	-106.7	IE	0.0001	21.2	0.0276	0.0002	-85.5
1995	-162.0	IE	0.0001	20.7	0.0255	0.0002	-141.2
1996	-223.6	IE	0.0001	23.9	0.0296	0.0002	-199.7
1997	-272.7	IE	0.0001	25.4	0.0309	0.0002	-247.3
1998	-314.1	IE	0.0002	26.0	0.0310	0.0002	-288.1
1999	-342.4	IE	0.0002	34.6	0.0440	0.0003	-307.8
2000	-366.9	IE	0.0001	42.5	0.0560	0.0004	-324.3
2001	-382.0	IE	0.0001	50.4	0.0681	0.0005	-331.5
2002	-398.4	IE	0.0002	45.3	0.0588	0.0004	-353.1
2003	-415.4	IE	0.0001	44.8	0.0575	0.0004	-370.5
2004	-430.2	IE	0.0001	42.2	0.0524	0.0004	-387.9
2005	-446.8	IE	0.0001	42.1	0.0515	0.0004	-404.6
2006	-463.1	IE	0.0001	38.8	0.0455	0.0003	-424.3
2007	-475.5	IE	0.0001	36.9	0.0420	0.0003	-438.5
2008	*-491.1*	*IE*	*0.0001*	*35.1*	*0.0382*	*0.0003*	*-456.0*
2009	*-511.8*	*IE*	*0.0001*	*35.7*	*0.0387*	*0.0003*	*-476.1*
2010	*-540.7*	*IE*	*0.0001*	*37.1*	*0.0406*	*0.0003*	*-503.6*
2011	*-561.6*	*IE*	*0.0001*	*36.6*	*0.0393*	*0.0003*	*-524.9*
2012	*-574.1*	*IE*	*0.0001*	*35.9*	*0.0376*	*0.0003*	*-538.1*

Table A4. 16: Removal and emissions of greenhouse gases by Article 3.4 Forest Management- Wales 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Fertilis-ation**	**Drainage**	**Biomass burning**	
1990	-762.0	-415.0	NO	3.971	0.017	NE	NE	0.000	-1172.6
1991	-827.9	-417.7	NO	8.176	0.036	NE	NE	0.000	-1236.6
1992	-941.8	-414.6	NO	2.081	0.009	NE	NE	0.000	-1354.1
1993	-1014.5	-410.9	NO	3.673	0.016	NE	NE	0.000	-1421.4
1994	-1072.5	-406.9	NO	2.998	0.013	NE	NE	0.000	-1476.1
1995	-1003.6	-405.5	NO	25.781	0.112	NE	NE	0.001	-1380.8
1996	-810.8	-411.1	NO	12.122	0.053	NE	NE	0.000	-1208.5
1997	-634.3	-415.3	NO	15.510	0.068	NE	NE	0.000	-1032.5
1998	-548.4	-412.6	NO	9.651	0.042	NE	NE	0.000	-950.4
1999	-381.1	-409.9	NO	1.415	0.006	NE	NE	0.000	-789.4
2000	-1016.8	-371.8	NO	5.397	0.024	NE	NE	0.000	-1382.7
2001	-1061.9	-357.8	NO	6.325	0.028	NE	NE	0.000	-1412.8
2002	-1106.7	-351.4	NO	5.098	0.022	NE	NE	0.000	-1452.5
2003	-1141.7	-346.6	NO	5.505	0.024	NE	NE	0.000	-1482.2
2004	-1167.3	-340.3	NO	5.698	0.025	NE	NE	0.000	-1501.4
2005	-1094.7	-334.4	NO	2.613	0.011	NE	NE	0.0001	-1426.2
2006	-1079.6	-327.4	NO	14.578	0.063	NE	NE	0.0004	-1391.0
2007	-1019.3	-323.3	NO	17.637	0.077	NE	NE	0.0005	-1323.1
2008	*-908.2*	*-321.3*	*NO*	*17.068*	*0.075*	*NE*	*NE*	*0.0005*	*-1210.7*
2009	*-799.4*	*-317.0*	*NO*	*8.434*	*0.037*	*NE*	*NE*	*0.0003*	*-1107.1*
2010	*116.8*	*-339.5*	*NO*	*8.950*	*0.039*	*NE*	*NE*	*0.0003*	*-212.8*
2011	*159.2*	*-331.7*	*NO*	*3.736*	*0.016*	*NE*	*NE*	*0.0001*	*-168.4*
2012	*82.8*	*-312.8*	*NO*	*6.985*	*0.031*	*NE*	*NE*	*0.0002*	*-222.3*

Table A4. 17: Removals and emissions of greenhouse gases by Article 3.3 Afforestation– N. Ireland 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Fertilis-ation**	**Drainage**	**Biomass burning**	
1990	-7.3	8.8	NO	IE	IE	0.0003	NE	IE	1.6
1991	-12.7	21.7	NO	IE	IE	0.0003	NE	IE	9.0
1992	-21.0	31.2	NO	IE	IE	0.0005	NE	IE	10.4
1993	-31.5	40.5	NO	IE	IE	0.0004	NE	IE	9.1
1994	-42.5	46.3	NO	IE	IE	0.0002	NE	IE	3.8
1995	-54.9	48.0	NO	IE	IE	0.0003	NE	IE	-6.7
1996	-67.5	48.8	NO	IE	IE	0.0003	NE	IE	-18.6
1997	-77.5	47.8	NO	IE	IE	0.0002	NE	IE	-29.7
1998	-86.8	46.4	NO	IE	IE	0.0002	NE	IE	-40.4
1999	-95.0	47.3	NO	IE	IE	0.0002	NE	IE	-47.7
2000	-100.8	47.1	NO	IE	IE	0.0001	NE	IE	-53.7
2001	-106.0	45.2	NO	IE	IE	0.0001	NE	IE	-60.8
2002	-110.6	42.3	NO	IE	IE	0.0001	NE	IE	-68.2
2003	-115.5	38.7	NO	IE	IE	0.0001	NE	IE	-76.7
2004	-119.4	34.2	NO	IE	IE	0.0000	NE	IE	-85.2
2005	-123.9	30.5	NO	IE	IE	0.0000	NE	IE	-93.4
2006	-126.8	25.9	NO	IE	IE	0.0000	NE	IE	-100.9
2007	-129.2	18.9	NO	IE	IE	0.0000	NE	IE	-110.3
2008	*-132.0*	*9.2*	*NO*	*IE*	*IE*	*0.0000*	*NE*	*IE*	*-122.8*
2009	*-133.3*	*-1.8*	*NO*	*IE*	*IE*	*0.0000*	*NE*	*IE*	*-135.1*
2010	*-133.7*	*-10.8*	*NO*	*IE*	*IE*	*0.0000*	*NE*	*IE*	*-144.5*
2011	*-132.6*	*-18.0*	*NO*	*IE*	*IE*	*0.0000*	*NE*	*IE*	*-150.7*
2012	*-129.8*	*-23.8*	*NO*	*IE*	*IE*	*0.0000*	*NE*	*IE*	*-153.6*

Table A4. 18: Removals and emissions of greenhouse gases by Article 3.3 Deforestation– N. Ireland 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**		**Net CO_2 eq. flux**
	Biomass	**Soils**	**Lim-ing**	**Biomass burning**	**Biomass burning**	**Deforestation to cropland**	**Biomass burning**	
1990	NO	NO	NO	NO	NO	NE	NO	NO
1991	NO	NO	NO	NO	NO	NE	NO	NO
1992	NO	NO	NO	NO	NO	NE	NO	NO
1993	NO	NO	NO	NO	NO	NE	NO	NO
1994	NO	NO	NO	NO	NO	NE	NO	NO
1995	NO	NO	NO	NO	NO	NE	NO	NO
1996	NO	NO	NO	NO	NO	NE	NO	NO
1997	NO	NO	NO	NO	NO	NE	NO	NO
1998	NO	NO	NO	NO	NO	NE	NO	NO
1999	NO	NO	NO	NO	NO	NE	NO	NO
2000	NO	NO	NO	NO	NO	NE	NO	NO
2001	NO	NO	NO	NO	NO	NE	NO	NO
2002	NO	NO	NO	NO	NO	NE	NO	NO
2003	NO	NO	NO	NO	NO	NE	NO	NO
2004	NO	NO	NO	NO	NO	NE	NO	NO
2005	NO	NO	NO	NO	NO	NE	NO	NO
2006	NO	NO	NO	NO	NO	NE	NO	NO
2007	NO	NO	NO	NO	NO	NE	NO	NO
2008	*NO*	*NO*	*NO*	*NO*	*NO*	*NE*	*NO*	*NO*
2009	*NO*	*NO*	*NO*	*NO*	*NO*	*NE*	*NO*	*NO*
2010	*NO*	*NO*	*NO*	*NO*	*NO*	*NE*	*NO*	*NO*
2011	*NO*	*NO*	*NO*	*NO*	*NO*	*NE*	*NO*	*NO*
2012	*NO*	*NO*	*NO*	*NO*	*NO*	*NE*	*NO*	*NO*

Table A4. 19: Article 3.3 ARD emissions and removals – N. Ireland 1990-2012

Year	**Afforestation**			**Deforestation**			
	Net CO_2 emissions/ removals Gg	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 emissions/ removals Gg**	**CH_4 emissions Gg**	**N_2O emissions Gg**	**Net CO_2 eq. emissions/ removals Gg**
1990	1.5	IE	0.0003	NO	NO	NO	1.5
1991	9.0	IE	0.0003	NO	NO	NO	9.0
1992	10.2	IE	0.0005	NO	NO	NO	10.2
1993	9.0	IE	0.0004	NO	NO	NO	9.0
1994	3.8	IE	0.0002	NO	NO	NO	3.8
1995	-6.9	IE	0.0003	NO	NO	NO	-6.9
1996	-18.7	IE	0.0003	NO	NO	NO	-18.7
1997	-29.7	IE	0.0002	NO	NO	NO	-29.7
1998	-40.4	IE	0.0002	NO	NO	NO	-40.4
1999	-47.7	IE	0.0002	NO	NO	NO	-47.7
2000	-53.7	IE	0.0001	NO	NO	NO	-53.7
2001	-60.8	IE	0.0001	NO	NO	NO	-60.8
2002	-68.3	IE	0.0001	NO	NO	NO	-68.3
2003	-76.8	IE	0.0001	NO	NO	NO	-76.8
2004	-85.2	IE	0.0000	NO	NO	NO	-85.2
2005	-93.4	IE	0.0000	NO	NO	NO	-93.4
2006	-100.9	IE	0.0000	NO	NO	NO	-100.9
2007	-110.3	IE	0.0000	NO	NO	NO	-110.3
2008	*-122.8*	*IE*	*0.0000*	*NO*	*NO*	*NO*	*-122.8*
2009	*-135.1*	*IE*	*0.0000*	*NO*	*NO*	*NO*	*-135.1*
2010	*-144.5*	*IE*	*0.0000*	*NO*	*NO*	*NO*	*-144.5*
2011	*-150.6*	*IE*	*0.0000*	*NO*	*NO*	*NO*	*-150.6*
2012	*-153.6*	*IE*	*0.0000*	*NO*	*NO*	*NO*	*-153.6*

Table A4. 20: Removal and emissions of greenhouse gases by Article 3.4 Forest Management- N. Ireland 1990-2012

Year	**CO_2 emissions/removals Gg**				**CH_4 emissions Gg**	**N_2O emissions Gg**			**Net CO_2 eq. flux**
	Biomass	**Soils**	**Liming**	**Biomass burning**	**Biomass burning**	**Fertilisation**	**Drainage**	**Biomass burning**	
1990	-625.3	-120.7	NO	13.628	0.059	NE	NE	0.0004	-731.1
1991	-623.0	-133.7	NO	9.676	0.042	NE	NE	0.0003	-746.1
1992	-633.8	-143.2	NO	2.445	0.011	NE	NE	0.0001	-774.3
1993	-573.7	-151.5	NO	4.224	0.018	NE	NE	0.0001	-720.6
1994	-592.8	-155.8	NO	2.802	0.012	NE	NE	0.0001	-745.5
1995	-546.5	-160.7	NO	1.903	0.008	NE	NE	0.0001	-705.1
1996	-521.4	-163.5	NO	11.363	0.050	NE	NE	0.0003	-672.3
1997	-506.1	-164.3	NO	16.609	0.072	NE	NE	0.0005	-652.1
1998	-479.5	-163.7	NO	2.753	0.012	NE	NE	0.0001	-640.2
1999	-475.9	-162.1	NO	1.160	0.005	NE	NE	0.0000	-636.7
2000	-486.4	-159.6	NO	0.796	0.003	NE	NE	0.0000	-645.1
2001	-508.5	-156.0	NO	11.517	0.050	NE	NE	0.0003	-651.9
2002	-484.5	-154.1	NO	11.877	0.052	NE	NE	0.0004	-625.5
2003	-435.5	-152.1	NO	0.144	0.001	NE	NE	0.0000	-587.5
2004	-435.1	-148.6	NO	13.244	0.058	NE	NE	0.0004	-569.2
2005	-370.1	-147.2	NO	2.283	0.010	NE	NE	0.0001	-514.7
2006	-344.5	-144.4	NO	12.4398	0.0543	NE	NE	0.0004	-475.2
2007	-267.5	-143.0	NO	14.8686	0.0649	NE	NE	0.0004	-394.2
2008	*-208.7*	*-139.9*	*NO*	*10.9724*	*0.0479*	*NE*	*NE*	*0.0003*	*-336.5*
2009	*-187.3*	*-135.5*	*NO*	*15.1186*	*0.0660*	*NE*	*NE*	*0.0005*	*-306.2*
2010	*-245.9*	*-127.6*	*NO*	*4.9609*	*0.0216*	*NE*	*NE*	*0.0001*	*-368.0*
2011	*-187.3*	*-124.4*	*NO*	*3.1115*	*0.0136*	*NE*	*NE*	*0.0001*	*-308.3*
2012	*-131.7*	*-122.4*	*NO*	*10.3808*	*0.0453*	*NE*	*NE*	*0.0003*	*-242.6*

24.5 Appendix 5: Photographs of AFBI blanket bog sampling sites

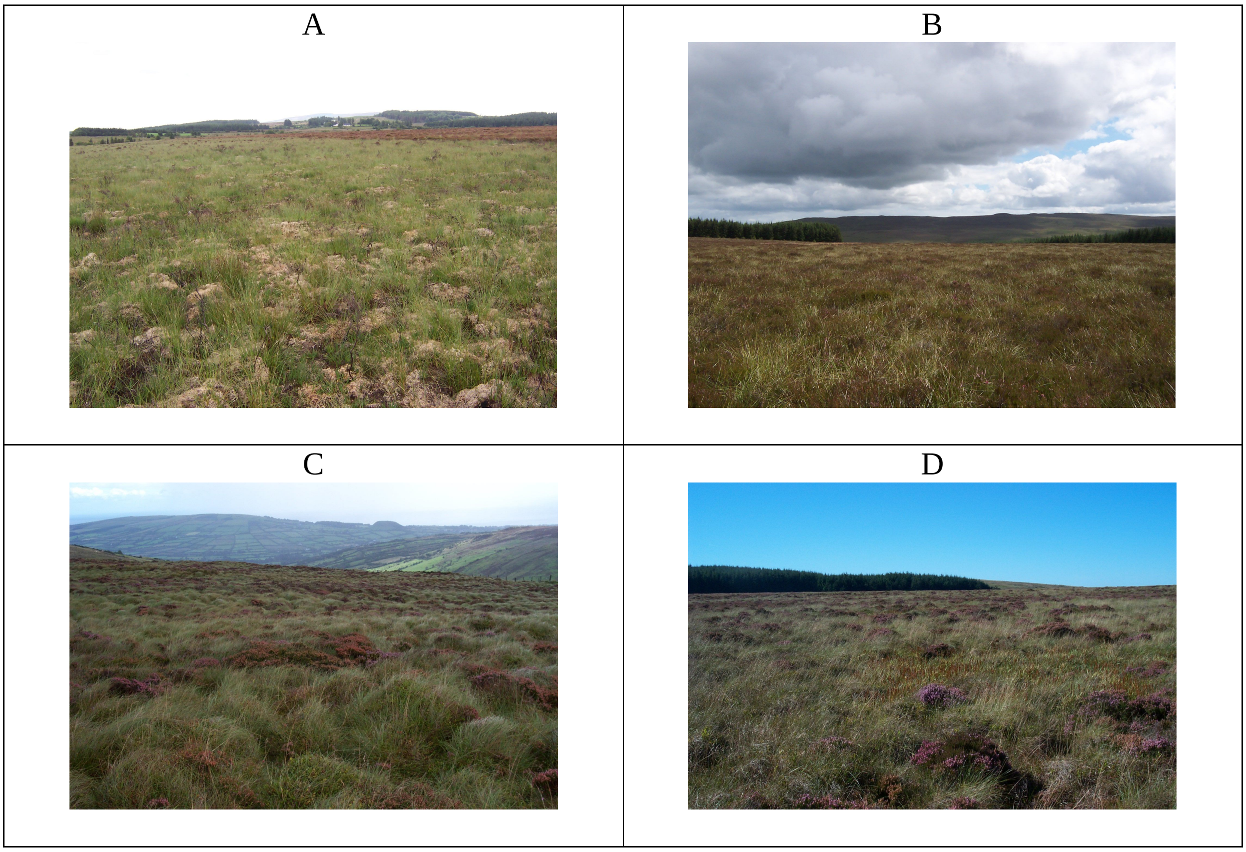

Figure 24-1: AFBI blanket bog sampling sites (A) Black Bog (grid ref 263234E, 381414N); (B) Slieveanorra Bog (grid ref 315214E, 427884N); (C) Sample point 5K469 (grid ref 319031E, 428463N); (D) Sample point 5K534 (grid ref 329597E, 405180N).