Report

Thomson, A. M.; Mobbs, D. C.; Milne, R.; Skiba, U.; Levy, P. E.; Jones, S. K.; Billett, M. F.; Van Oijen, M.; Ostle, N.; Foereid, B.; Smith, P.; Randle, T.; Matthews, R. W.; Gilbert, J.; Halsall, L.; Brewer, A.; Baldwin, M.; Mackie, E.; Bellamy, P.; Rivas-Casado, M.; Bradley, R. I.; Grace, J.; Lewis, P.; Quaife, T.; Jordan, C.; Tomlinson, R. W.. 2007 ***Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry. Annual Report June 2007.*** **Edinburgh, UK, CEH/Defra, 200pp. (CEH Project Number: C03116)**

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

Annual Report, June 2007

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 2006 - May 2007 (WP1.1-1.4 & WP6)

The 1990-2005 greenhouse gas inventory estimates for the LULUCF sector (and supporting text for the National Inventory Report) have been 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 April 2007.

There was estimated to be a net emission of 2882 Gg CO_2 from the LULUCF sector in the UK in 1990, but this flux had changed to a net removal of -2056 Gg CO_2 by 2005. There were only small differences from the estimates in the 1990-2004 inventory; these are due to revision of the data on conversion of Forest Land to Settlement and other minor data revisions and corrections. There were no major methodological changes for this submission.

For the separate countries, England is a net emitter between 1990 and 2005 (although on a downwards trend), while Scotland and Northern Ireland are net removers (with removals increasing 1990-2005). Wales has a small net removal but does not have the strong trend shown in the other countries. There is an MSc student project underway to assimilate data and construct inventories for the Overseas Territories and Crown Dependencies, which will be completed by the end of August 2007.

We also produced Common Reporting Format tables of Kyoto Protocol activities (Art. 3.3 Afforestation, Reforestation and Deforestation and Art. 3.4 Forest Management) for the first time for voluntary submission to the UNFCCC in April 2007. Supplementary information on these tables was included in the 2007 National Inventory Report submission (Annex 10). New methods for reporting Kyoto Protocol estimates at more detailed spatial scales (20x20km rather than national) are in development.

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 1990-2005.

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 2006 - May 2007 (WP2)

WP2.1 Improved operational methods for inventory calculations

The current system of spreadsheets has been streamlined and made more transparent with additional comments embedded with the data. Some Matlab scripts have been written to accurately compile the key data for submission. Work on the proposed 'report generator' software was postponed due to changes in the latest release of the CRF Reporter software making the original design less useful. A new specification has been designed and will be completed in August.

The inventory manual, for internal CEH use, has been converted to a web-based 'wiki' making it more accessible to staff. The documentation and workflow procedures can be updated more efficiently by anyone working on the project, with new information immediately available to all colleagues. Task and issue management software is being considered for use in Year 2.

WP2.2 Incorporation of N_2O and CH_4 emissions and removals due to LULUCF

Emissions of non-CO_2 greenhouse gases in the LULUCF Sector come from: (i) biomass burning as part of deforestation producing CH_4 and N_2O emissions, (ii) application of fertilisers to forests producing N_2O and (iii) disturbance of soils due to some types of land use change producing N_2O associated with CO_2 emissions. Emissions due to biomass burning are already included in the inventory but emissions from the other activities are not.

The global warming potential of N_2O is large (310) so it is therefore of considerable importance that the methodology used is scientifically sound. This does not appear to be the case for the IPCC default methodology for estimating N_2O emissions from soil disturbance, as there are few available measurements and poor understanding of the relevant processes. It is therefore prudent to await an alternative approach for estimation before including any data in the inventory. Research is being undertaken to measure change in stocks of soil carbon and nitrogen due to ploughing of an upland grassland (WP 2.6), which should increase understanding in this area.

The data on fertiliser applications to forests between 1990 and 2005 is not yet complete but the use of fertilisers and sewage sludge on forests in 2005 is estimated to have caused emission of 30.425 tonnes N_2O. This gives an equivalent CO_2 emission of 9.4 Gg, which is very small compared to other emissions and removals in the LULUCF Sector.

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.

Spatial variation in planting patterns under different ownership types has been investigated using detailed data sources from the various forestry agencies to construct forest planting time series from 1990 to 2005 at the 20km grid cell scale. This mapped data is an improvement on the national planting statistics used until now, and has particular relevance for the estimation of carbon fluxes from Afforestation under Article 3.3 of the Kyoto Protocol.

Draft scenarios of forest management in the devolved regions have been developed. These include taking account of revised assumptions about restocking of existing forests to diversify composition, improved estimates of yield class distribution by species and better representation of new forest management regimes, notably "Low Impact Silvicultural Systems".

Predictions of the 2005 and 2006 timber production forecasts (PF) were reviewed and the implications for projections of forest carbon stocks were considered. The 2006 forecasts have changed indistinguishably from the 2005 forecasts. On the other hand, the 2005 PF represented a major revision of the 2000 PF, improving representation of the forest estate and its management through: more complete and accurate stand data; more comprehensive management plans; and appropriate representation of intended management. These improvements and chaged assumptions have resulted in some notable changes in forecasts of timber volume availability compared to the 2000 PF. Impacts on estimates of the growing (carbon) stock in the GB forests are likely to mirror these changes in estimates of production. The potential sensitivity of the forecast results to uncertainties in these data and assumptions about future management emphasises the requirement for a robust, verifiable forecast methodology.

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

A stand assessment protocol for use in national forest inventories has been developed which is capable of providing estimates of forest carbon stocks. The monitoring methodology of forest carbon stock and stock changes is intended to integrate with the second FC National Inventory of Woodland Trees (NIWT2). The main focus will be to determine properties of woodlands over a large geographic area by aggregating the results of observations made on the individual plots – thus, there is less intrinsic interest in the properties of any individual plot forming the sample. Brewer *et al.* (2006) have described the main inventory plot assessment protocol, which permits estimating of a range of tree and stand variables including carbon stocks.

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. The Scottish Forestry Alliance manage nine sites in Scotland where recent planting has taken place, and baseline surveys of soil carbon have been carried out at the time of planting (Meir *et al*, 2003). At a sub-set of these sites, we propose to measure soil carbon in stands of varying age, and compare this with the baseline data quantifying the soil carbon prior to planting. The priority sites to be re-sampled will be Abernethy Forest Reserve, Glen Finglas, Glen Sherup and Geordie's Wood, and an experimental plan has been produced, based on the baseline survey. The field work is planned for summer 2008.

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. The previous report described the setting up of the experiment and the pre-treatment measurements of soil carbon and soil respiration. Since May 2006, the annual cultivation treatment has been applied, and measurements of CO_2, N_2O and CH_4 fluxes made. An attempt to measure the ^{14}C component in respired CO_2 was made in November 2006 but failed to capture enough CO_2 for ^{14}C analysis. A modification to the method to increase the capture of CO_2 is currently being tested (May 2007). Chamber flux measurements showed i() no significant difference in CH4 fluxes, (ii) significantly higher N_2O emissions in the uncultivated treatment, and (iii) higher CO_2 emissions in the uncultivated treatment which were close to significant levels. Without the measurements of soil carbon loss planned for year 3, we cannot draw definite conclusions about the impact of cultivation on the overall greenhouse gas balance, but the results to date show that some effects are significant.

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. The original experimental plan was to measure the carbon balance on a drained site, before and after drain blocking. However, after extensive searching and consultation with land owners, no suitable sites could be found where drain blocking is planned in the next few years.

Instead, we plan, and are in the process of setting up, a three-way comparative experiment with sites that are pristine, drained, and drain-blocked, at the RSPB reserve at Forsinard, Sutherland. The original 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 comparison 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. The use of three sites necessitates a change in methodology, as there is only one eddy covariance system for measuring landscape-scale CO_2 fluxes. The eddy covariance system will be located at the pristine site, to give the background flux for the undisturbed state. Surface fluxes will be measured using chambers at all three sites, as this allows replication and statistical analysis of between-site differences. The fluvial fluxes will be measured at all three sites by monitoring discharge rates and total carbon content in fortnightly water samples. Sites were selected in May 2007 and will be instrumented from June 2007. A postdoctoral fellow at the Environmental Research Institute, Thurso, will carry out the bulk of water sampling and chamber flux work.

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 and 40% of which were resampled between 1995 and 2003. Only a broad land use class was associated with each of these sites at the time of sampling. The first objective of WP2.8 was to try to identify those NSI sites where other sources of land management information could give us information of the history of land management at the NSI site both before sampling and over the interval between samples.

It appears there is not as much information on land management at the NSI sites as we had hoped although 14 NSI sites have been identified with some land management information and 28 sites not in the NSI but with similar resampling that have details of land management. We do not yet have information on the Forest Inventory but expect that this will give us information on management of woodlands over the sampling period which even if not from the same sites should be applicable to those NSI sites that have remained under woodland between the two samplings. There are 123 resampled NSI sites under deciduous/mixed woodland and 111 NSI sites under coniferous woodland.

Monthly records of climate have been obtained for every NSI point from 1960 to 2005 and work is progressing on investigating the building of soil moisture records in collaboration with the NERC funded project ‘An improved empirical model of soil carbon dynamics in temperate ecosystems’

Investigations have been made into possible statistical techniques that could be used to model the relationships between the change in organic carbon at the selected sites and other soil and climate properties and land management. We will use hierarchical models to represent the repeat sampling and to enable us to include the additional information available at each site.

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

The code for the coupled soil and vegetation model RothC-Biota has been simplified, and simple documentation has been produced. The model has been made able to respond to more environmental factors through the implementation of limitations to plant production due to fertiliser application and drought. Plant allocation has also been made more flexible. Data for parameterisation have been collected, and parameterisation and testing against data and other models, e.g. JULES, are underway. The ECOSSE model has been tested against various agricultural data sets.

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

The primary objective of WP2.11 is to analyse the influence of changes in climate on the fluxes of carbon arising from land use change. To do this, we will use mechanistic models which represent the processes affected by climate, and perform simulations with and without climate change to calculate the effect on LULUCF carbon fluxes. We can thereby 'factor out' the component of the LULUCF flux which results from anthropogenic climate change. The secondary objective is to repeat this for other indirect factors such as CO_2 and nitrogen deposition. The first task is to produce the input data sets required by the two models for these simulations. The key inputs are land use, land use change, climate, soil nitrogen, and nitrogen deposition, all on a 20km grid covering the UK. This is largely complete for climate, and relatively straightforward for land use change and nitrogen deposition. An MSc student from University of York (Andrew Clark) will work on this project for three months from June 2007 as a summer placement, and is expected to complete the input data sets and perform the preliminary model runs. The simulations may need to be repeated later in the project if the estimated land use change matrices change as data analysis proceeds in related work packages.

WP2.12 Inventory projections of harvested wood products

The scope for development of a system for modelling carbon stocks and carbon dynamics of harvested wood products (HWP) has been considered and specified. At least four different approaches to account for carbon in HWP are under consideration. Any system for modelling (HWP) carbon stocks needs to be flexible enough to work with any of the proposed reporting approaches. The Forestry Commission commissioned Forest Research to prepare a plan for the development of an upgraded and improved FC forecast system. This system has been designed to facilitate many types of forecast, including estimates of current and future carbon stocks in wood products.

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

The structure of the annual transition probability matrix between 5 land use types (Arable land, Grassland, Woodland, Developed land and Other land) has been described. Variation of probabilities over time can be included by using stochastic model for matrix elements.

Annual land area data for England for period from 1990 to 2005 for arable, grassland, woodland, developed and other land has been obtained for model testing purposes. The land use change transition matrix for these land types in England between 1990 and 1998 has been obtained from Countryside Surveys for use as basis for estimation of transition probability matrix.

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.

The first annual workshops has been delayed because of related Carboeurope meetings and discussions about the establishment of an infrastructure for a Europe-wide GHG-carbon monitoring system based also on models, flux towers and atmospheric measurements. The observational system would provide verification of GHG fluxes for European countries, dis-aggregation of fluxes into biogenic and anthropogenic components, and identification of the fluxes associated with particular land cover. The data and associated models would therefore enable 'what if' experimentation regarding the impact of making changes in land use.

WP2.15 Design of greenhouse gas observing systems

The aim of WP2.15 is to develop designs for a national/regional GHG observing system. This involves the use of ground, tall tower and airborne flux measurements and the constraint of national/regional fluxes by modeling and airborne and satellite data assimilation.

The key to integrating process understanding and all of these measurements is a suite of models. We use two main models in this work: (i) SDGVM, an ecological model that represents our current understanding of soil and vegetation processes and which will predict C stocks and fluxes, given the vegetation type and climate data; (ii) DALEC, a simpler ecological model that represents the main processes and C fluxes that is more suitable constraining with a large number of observations and for learning how to assimilate various forms of data. We have made significant progress this year in developing various aspects of the SDGVM, in particular a new module for modelling organic soils. This work is backed up by several ground measurement campaigns to allow the model to be tested under different conditions and develop our understanding of processes. We have also made significant progress this year in understanding how to combine low-level satellite products into the DALEC model, which does a good job of tracing the uncertainties inherent in the observations through to the estimates of C fluxes and stocks.

WP2.16 Soil carbon and peat extraction in Northern Ireland

The first systematic survey of the soils of Northern Ireland was carried out between 1988 and 1997, with sampling of predominantly agricultural soils done on a near regular 5km grid. In winter 2004-05, soils were re-sampled on the same 5km grid but extended to include soils from all regions: agricultural, semi-natural, upland and urban. In all, 582 soils were sampled in 2004-05 (an additional 103 samples compared with the 1988-97 survey) and subjected to physical and chemical analysis including total Carbon (%C). The complete dataset of %C results for the re-survey are now available.

The conclusions drawn from analysis of this dataset are that most (about two-thirds of) grassland soils in Northern Ireland have been slowly accumulating C at an annual average rate of about 1% of their original value. In contrast, arable and some managed grassland soils (those with a change in land use since 1995 or having had a recent reseed), in Northern Ireland have been losing C at an average annual rate of about 0.4% and 1.4%, respectively. These conclusions have important implications for the updating of the soil C inventory values for Northern Ireland. Bulk density measurements (taken from top 50mm; volume 222cm^3) for each sample from the 2004-05 survey are nearing completion and should help improve the accuracy of the carbon load estimate in the topsoils of Northern Ireland.

A sampling network for fuel peat extraction has been derived. A 5% random sample of 1km x 1km grid squares from the Northern Ireland Peatland Database (excluding Co. Down and east Co. Armagh where because of physical conditions there is no machine peat cutting, nor likely to be) gave 85 grid squares with lowland peat and 25 incidences of machine fuel cutting (approx. 6% of lowland incidences). For blanket peat the sample gave 121 grid squares and 52 incidences (approx. 5% of blanket incidences).

Due to the start date of the project, by the time field survey could begin the cutting season had largely been missed; it was not possible to achieve the first one-third of field sampling. Instead, work on horticultural extraction was moved forward. The first stage was to review and revise previous estimates of carbon loss in 1991. In the 1996 Report the estimate was based on volumes of peat extracted using information from planning applications. Subsequently, it proved difficult to obtain similar data; also, because the estimated carbon losses were derived from forecast volumes given in the planning applications they did not necessarily reflect the subsequent productive areas. Using our existing database of peat extraction (identified from satellite images and field visits) which gave areas for each site, and assuming an annual removal of 10cm of peat and a C content of 5.08 kg/100 litres, the estimated C extraction in 1991 was 38,456 tonnes C. This compares with 31,902 tonnes estimated in the 1996 Report.

Satellite imagery for 2001 has been examined and sites of horticultural extraction identified and measured (checking is not complete). Using the same procedures as for 1991, this has produced an *interim* C extraction of 37,389 tonnes. The procedures will be repeated for the latest imagery available close to the end of the contract.

It appears that C losses from horticultural peat extraction in 2001 were similar to those in 1991. Bearing in mind changes in methodology (including advances in image interpretation and measurement of sites), and that some sites remain to be confirmed (including changes in type of extraction), C losses from horticultural peat extraction in 2001 are not too dissimilar from those reported in 1996.

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 2006 - May 2007 (WP3)

The method selected for uncertainty quantification in WP3 is Bayesian. In year 1, an extensive literature review was carried out to determine to what extent the Bayesian approach is consistent with methods used by other parties. The conclusion of this review was that the many guidelines, protocols and standards presented in the literature (IPCC, ISO, NIST, WBCSD/WRI and others) are all fully consistent with the Bayesian approach. All recommended methods begin by quantifying uncertainty in the input factors used in calculations and determine how that uncertainty propagates through to the outputs, i.e. the emissions and removals of GHG in the case of the inventory. The Bayesian approach extends this common approach by providing a means to include additional information, on directly and indirectly variables, to significantly reduce the uncertainties. The second major activity of year 1 was to assess the available information on input variables and their uncertainty, and sufficient sources of information were identified – publications as well as web-databases – to allow testing of the uncertainty calculation methods in year 2. Finally, WP3 exchanged information in year 1 with the related work packages WP's 2.11 and 2.13, which apply Bayesian uncertainty quantification to process-based modelling of forests and to quantifying land-use change matrices.

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 2006 - May 2007 (WP4)

CEH has participated in the UK national system meetings as technical experts for LULUCF. We have maintained regular communication with AEA, the contractor responsible for the total UK inventory. We also contributed to the week-long UN in-country review of the UK's inventory and initial report under the Kyoto Protocol in March 2007, and responded to all of the reviewer's questions in a comprehensive and timely fashion. We also responded as required to the UN desk-based review of the inventory in January 2007.

CEH, and other project partners, have taken part in a number of research collaborations relevant to the inventory during the 2006/07 project year. These include national collaborations, e.g. the ECOSSE project (SEERAD/WAG), LULUCF mapping at the local authority scale for AEA, QUEST (NERC), and international collaborations, e.g. NitroEurope IP, CarboEurope IP, COST639 on "Greenhouse gas budget of soils under changing climate and land use".

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 2006 - May 2007 (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. Ten meetings, ranging from local to IPCC, were attended and/or presented at. There were a large number of requests for advice/information: 13 from Defra, 8 from devolved administrations/government agencies, 9 from the general public and one from the media. We responded promptly to these requests and coordinated responses from a broader range of CEH staff or project partners as required. Six publications arose from the inventory project and associated research, with a further 8 in press. It is expected that further publications will be produced as the contract proceeds.

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

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1.1 Introduction

This section describes the 2005 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 2005 to some –2056 Gg 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.

Net emissions in 1990 are estimated here to be 2882 Gg CO_2 compared to 2915 Gg CO_2 in the 2004 National Inventory Report. For 2004 a net removal of -1935 Gg CO_2 is estimated here compared to a net removal of -1942 Gg CO_2 in the 2004 Inventory. These small differences are due to revision of the data on conversion of Forest Land to Settlement, which affected the land use transition matrix, and other minor data revisions and corrections described under each category.

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.

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.

1.2.1 Category 5A- Forest Land

All UK forests are classified as temperate and about 65% 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.

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

There are about 822,000 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 2005. The Forestry Commission/Forest Service have also provided spatially disaggregated planting statistics for the first time this year but the methodology for including these data in the main inventory is still under development.

Methodology

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 1920 to 2005 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 did 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 and an expo-linear curve for growth before thinning. It was assumed that all new conifer plantations have the same growth characteristics as Sitka spruce (*Picea sitchensis* (Bong.) Carr.) under an intermediate thinning management 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. It can be shown that, if forest expansion continues at the present rate, removals of atmospheric carbon will continue to increase until about 2005 and then will begin to decrease, reflecting the reduction in afforestation rate after the 1970s. This afforestation is all on ground that has not been under forest cover for many decades. Table 1-1 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 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 1-1: Afforestation rate and age distribution of conifers and broadleaves in the United Kingdom since 1921. The afforestation rates and ages of GB forests planted later than 1989 are from planting records but 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 Northern Ireland forests is estimated from planting records.

Period	**Planting rate (000 ha a^{-1})**		**Age distribution**	
	Conifers	**Broadleaves**	**Conifers**	**Broadleaves**
1921-1930	5.4	2.4	1.4%	7.9%
1931-1940	7.5	2.1	2.5%	8.5%
1941-1950	7.4	2.2	6.1%	11.9%
1951-1960	21.7	3.1	16.3%	11.6%
1961-1970	30.1	2.6	22.6%	8.4%
1971-1980	31.4	1.1	22.3%	5.9%
1981-1990	22.3	2.2	19.0%	4.9%
1991	13.4	6.8	0.9%	0.6%
1992	11.6	6.5	0.8%	0.6%
1993	10.1	8.9	0.7%	0.8%
1994	7.4	11.2	0.5%	1.0%
1995	9.5	10.5	0.7%	1.0%
1996	7.4	8.9	0.5%	0.8%
1997	7.8	9.5	0.5%	0.9%
1998	7.0	9.7	0.5%	0.9%
1999	6.6	10.1	0.5%	0.9%
2000	6.5	10.9	0.5%	1.0%
2001	4.9	13.4	0.3%	1.3%
2002	3.9	10.0	0.3%	0.9%
2003	3.7	9.3	0.3%	0.9%
2004	2.9	8.9	0.2%	0.8%
2005	2.1	9.2	0.2%	0.9%

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 1-2, 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 its own (slower) rate. Both 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.

Table 1-2: 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 was 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 the new National Inventory of Woodland and Trees should become available from 2009, which will allow the verification of carbon stock estimates from the C-Flow model.

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.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 area associated with each set of disaggregated data is included in Sectoral Background Table 5.A.2.

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”.

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. Work is now underway to construct the spatially disaggregated data sets, with GB data sets back to 1990 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. The results of this work should be incorporated into the modelling framework of the inventory by 2009.

1.2.2 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 as a study has shown these to be small (Skiba *et al.* 2005). This assessment has been re-examined this year and is discussed in 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 BGS (2006). Estimates of the individual materials are provided by the British Geological Survey each year as only their total is 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.

The published data includes ‘material for calcination’, which only refers to dolomite. However, some of this calcinated dolomite is not suitable for steel making and is returned for addition to agricultural dolomite – this fraction is reported in BGS (2006) as ‘material for calcination’ under agricultural end use. Calcinated dolomite, having already had its CO_2 removed, will therefore not cause the emissions of CO_2 and hence is not included here. Lime (calcinated limestone) is also used for carbonation in the refining of sugar but this is not specifically dealt with in the UK LUCF GHG Inventory.

Lime is applied to both grassland and cropland. The annual percentages of arable and grassland areas receiving lime in Great Britain for 1994-2004 were obtained from the Fertiliser Statistics Report 2006 (Agricultural Industries Confederation 2006), and extrapolated to obtain an estimate for 2005. 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 1-3). 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 1-3: 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 (126,000 ha)	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.1 (Cropland remaining Cropland) under carbon stock change in living biomass. The area of land associated with each set of data is also included in Sectoral Background Table 5.B.1.

The emissions in this Category 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 Cropland (and Grassland).

The emissions in this Category due to lowland drainage are entered into Sectoral Background Table 5.B.1 (Cropland remaining Cropland) under net carbon stock change in soils. This applies only to England so there is no further disaggregation. The area of land associated with lowland drainage is also included in Sectoral Background Table 5.B.1. Emission of CO_2 from drained lowland fens were reported in Category 5D5 (CO_2 Emissions and Removals - Other).

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 1-4) 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 1-5 to Table 1-8), 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 1-4: 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 1-5: 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 1-6: 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 1-7: 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 1-8: 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. Land use in the UK was placed into the GPG categories – Forestland, Grassland, Cropland, Settlements, and Other Land by combining the more detailed categories for the two surveys (Table 1-9 and Table 1-10). The data currently available for the UK does not distinguish wetlands from other types, so land in the UK has been placed into the five other types. Area change data exist for the period up to 1998 and those from 1990 to 1998 are used to extrapolate to the years 1999 to 2005 (Table 1-11).

Table 1-9: 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 1-10: 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 1-11: 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 - 2004	*Extrapolated*	CS1990 → CS1998

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 1-12).

Table 1-12: 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

For both Great Britain and Northern Ireland the land use change data over the different periods were used to estimate annual changes by assuming that change was uniform across the measurement period. Examples of these annual changes (for the period 1990 to 1999) are given in Table 1-13 to Table 1-16. The data for land use change to and from Forest Land shown in the Tables are adjusted before use for estimating carbon changes to harmonise the values with those used for afforestation and deforestation (described elsewhere).

Table 1-13: 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 1-14: 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 1-15: 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 1-16: 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.

To \ From	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, based on information on soil type, land cover and carbon content of soil cores, has been available since 1995 (Milne & Brown 1997, Cruickshank *et al.* 1998). These densities included carbon to a depth of 1 m or to bedrock, whichever was the shallower, for mineral and peaty/mineral soils. Deep peat in the North of Scotland was identified separately and depths to 5 m are included. For the 2003 Inventory a complete re-evaluation of the database was carried out (Bradley *et al.* 2005). The 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 1-17 and Table 1-18.

Table 1-17: Soil carbon stock (TgC = MtC) for depths to 1m under the IPCC land categories

Type \ Region	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 1-18: 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 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 parameters selected from within the ranges described above. 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. The rate of loss or gain of carbon is dependent on the type of land use transition. 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 1-19 to Table 1-22.

Table 1-19: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in England

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

Table 1-20: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Scotland

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

Table 1-21: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Wales

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

Table 1-22: Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m deep for changes between different land types in Northern Ireland

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

The rate of loss or gain of carbon is dependent on the type of land use transition (Table 1-23). 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 1-24).

Table 1-23: Rates of change of soil carbon for land use change transitions. ("Fast" & "Slow" refer to 99% of change occurring in times shown in Table 1-24)

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

Table 1-24: 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.2 Land Converted to Cropland. The area of land associated with each set of data is also included in Sectoral Background Table 5.B.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.B.2 Land converted to Cropland. 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 areas of land associated with each set of data are also included in this Table.

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 is being undertaken for England.

Sampling of the National Soil Inventory between 1978 and 2003 (Bellamy *et al*. 2005) has found large losses of carbon from soils across England and Wales. Work is now underway to assess the relative contributions of land use and management and climate change (and their interaction) to these soil carbon losses. This should produce an estimate of the likely magnitude of past changes in soil organic carbon under different management scenarios and the relative importance of the various drivers of those changes (by 2009). There will then be an assessment as to whether the inventory methodology needs to be adapted in the light of these results. A soil carbon inventory project is underway for Northern Ireland, the results of which will be incorporated into the inventory methodology.

New versions of the GB and Northern Ireland Countryside Surveys are underway, with results due in 2008. 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 is currently in progress (Work Package 2.6). The results from this work will be used to verify assumptions in the land use change model and to modify the model if necessary.

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

1.2.3 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.B.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.B.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 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 used in horticulture is now reported in the LULUCF sector. Peat used as a fuel 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 2005 have been estimated from activity data taken from the UK Minerals Handbook (BGS 2006). 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 2005. Peat extraction is negligible in Wales. Emissions factors for this activity are from Cruickshank & Tomlinson (1997) and are shown in Table 1-25**.**

Table 1-25: 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 in this Category 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 in this Category due to peat extraction are entered into Sectoral Background Table 5.C.1 Grassland remaining Grassland, disaggregated into the four geographical areas of England, Scotland, Wales and Northern Ireland.

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 is underway and due to be completed by 2009 (work package 2.16).

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 2003-2005 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 (Department of Communities and Local Government, 2006, previously the Office of the Deputy Prime Minister) from the data it collects for map updating. Eleven broad land-use categories are defined, with a number of sub-categories. The data for England (1990 to 2005) 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 CO_2, CH_4 and N_2O 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 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 2005. Data on rural deforestation is only available up to 2002; therefore areas for 2003-2004 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.2 Land Converted to Grassland. The area of land associated with each set of data is also included in Sectoral Background Table 5.C.

Net carbon stock change in soils resulting from land use change is included in Sectoral Background Table 5.C.2 Land converted to Grassland. 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).

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.

1.2.4 Wetlands (5D)

In the UK, Wetlands will either be saturated land (e.g. bogs, marshes) and, due to the classifications used in the Countryside Survey, will fall into the Grassland category or into 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).

1.2.5 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 in two time periods, 1950-1989 and 1990 onwards.

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).

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.

1.2.6 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).

1.2.7 Other Activities (5G)

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

Methodology

The carbon uptake by the forests planted since 1920 is calculated by a carbon accounting model (C-Flow) as the net change in the pools of carbon in standing trees, litter, soil and products from harvested material for conifer and broadleaf forests. The method is Tier 3, as defined in the GPG LULUCF (IPCC 2003). The model calculates the masses of carbon in the pools of new even-aged plantations that were clear-felled and then replanted at the time of Maximum Area Increment. Only products from UK forests planted since 1920 (i.e. those for which biomass and soil carbon stock changes are reported) are considered at present. It is not considered to be of high priority to consider the decay of imported products etc. as there is no 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). A carbon stock loss of 5% is assumed to be lost immediately at harvest.

Subsequently, the decay time (time to 95% loss of carbon stock) of products is set equal to the rotation time for that species. This approach captures differences in wood product use: fast growing softwoods tend to be used for shorter lived products than slower growing hardwoods. Exponential single decay constants are used for HWP from conifers and broadleaves. Products from thinnings are assumed to have a lifetime (time to 95% loss) of 5 years (half life~0.9 years). The main harvest products have a lifetime equal to rotation length. For conifers this equates to a half life of 14 years and for broadleaves a half life of 21 years. These 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 products in the UK when the model was originally developed. The mix of products may be changing in the UK and this could affect the 'true' mean value of product lifetime but there is very limited accurate data on either decay rates or volume statistics for different products. The method used in the UK takes a top-down approach by assuming that the decay of all conifer products and all broadleaf products can be approximated by separate single decay constants. Given the uncertainty on decay of products it is difficult to decide if this is better or worse than a bottom-up approach where each product is given an (uncertain) decay and combined with (uncertain) decay of other products using harvest statistics which are in themselves uncertain.

Calculated in this way, the total wood products pool from UK forests is presently increasing due to continuing expansion in forest area. The time pattern of HWP stock changes is due to the historical pattern of new planting and by the resulting history of production harvesting (and thinning). The stock of carbon in HWP (from UK forests planted since 1920) has been increasing since 1990 but this rate of rise has recently reversed, reflecting a dip in new planting during the 1940s. The stock of carbon in HWP will fall for a few more years but will then begin to rise steeply due to harvesting of the extensive conifer forests planted between 1950 and the late 1980s.

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 is currently being undertaken to verify the modelled Harvested Wood Products by comparison with the Forestry Commission Production Forecast.

1.3 Results

Data for the 1990 to 2005 GHG Inventory are presented in Appendices 1 to 4 of this volume. The data for this period (2006 Inventory submission date) are summarised in Table 1-27.
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 2005 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 post-1990 afforestation and deforestation in the UK

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 2005. 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.

1.3.1 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 820,000 ha of forest that has existed since before 1920 and is also assumed to be in carbon balance because of its age and therefore has zero stock change.

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

All afforestation (1,652,900 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 2005. Net carbon stock changes resulting in atmospheric removals have varied over time: starting from -12,203 Gg in 1990 and reaching a maximum of -16,302 Gg in 2004. The net carbon stock change in 2005 was -15,738 Gg. These changes reflect variation in planting rates in past decades which feed through growth and harvesting to the carbon uptake trends reported here.

1.3.2 Cropland (5B)

Cropland Remaining Cropland (5.B.1)

Changes in carbon stocks resulting from changes in non-forest biomass resulting from yield improvements, application of lime and lowland drainage are reported in this category. There were no changes in the methodology but some revisions of the liming activity data and updating with 2005 data (BGS 2006). Minor revisions in the agricultural census dataset resulted in changes in the allocation of lime to either Cropland or Grassland. Estimated emissions from Cropland have fallen by 11 Gg CO_2 in 2004 compared with the numbers for 2004 in the previous submission (2006 NIR). However, total emissions from the application of lime remain the same, only the allocation to land use has changed.

Overall, the carbon stock changes in this category result in net emissions, which appear to be on a downward trend, starting from 1802 Gg in 1990 (with a peak of 1947 Gg in 1991) to 964 Gg in 2005. This trend is mainly driven by the declining emissions from lowland drainage, which have fallen steadily from 1650 Gg in 1990 to 1173 Gg in 2005. 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 some minor recalculations from the 2004 inventory. An error in the non-forest biomass matrix for Wales has been corrected. This resulted in a change in emissions of -0.084 Gg CO_2 per year. Although no recalculations were undertaken for changes in soil carbon stocks the nature of Monte Carlo simulation results in minor differences in emissions/removals between years.

Emissions from land converted to Cropland show a small but steady rate of increase, from 14,034 Gg in 1990 to 14,294 Gg in 2005. This trend is due to changes in soil carbon stocks as changes in non-forest biomass stocks occur at a fixed rate.

1.3.3 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 updated with 2005 data (BGS 2006). Minor revisions in the agricultural census dataset resulted in changes in the allocation of lime to either Cropland or Grassland. Estimated emissions from Grassland have risen by 11 Gg CO_2 in 2004 compared with the numbers for 2004 in the previous submission (2006 NIR). However, total emissions from the application of lime remain the same, only the allocation to land use has changed.

Emissions from this category are variable over the time period, starting at 1,028 Gg in 1990, with a peak of 1,256 Gg in 1995, and then falling away to 564 Gg in 2002, with an emission of 692 Gg in 2005. 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. Data on rural deforestation (Forest Land converted to Grassland) is only available up to 2002; therefore areas for 2003-2005 were estimated by extrapolation from earlier years. The revision of the deforestation dataset also resulted in a re-allocation of areas in the land use change matrix, producing changes in emission/removal estimates from those in the 2004 National Inventory Report. The nature of Monte Carlo simulation also results in minor differences in emissions/removals between years. There was a change of -32 Gg CO_2 in 2004 (compared with the estimate for 2004 in the 2006 NIR).

Overall, this category results in a net removal from the atmosphere, which has increased over time, from -7,228 Gg in 1990 to 8,627 Gg in 2005. 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}).

1.3.4 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. There were some revisions of activity data for this category. The data on the area of deforestation in non-rural areas have been revised for each year from 1990-2003. A five-year moving average (a three-year moving average was previously used) has been applied on the recommendation of the data suppliers (Department of Communities and Local Government). The area of deforestation in 2004 and 2005 has been estimated by extrapolation from earlier years. These revisions have resulted in a change of 31 Gg CO_2 for 2004 compared with the 2004 estimate submitted in the 2006 NIR. The revision of the deforestation dataset resulted in a re-allocation of areas in the land use change matrix, producing a change of 11 Gg CO_2 in emission/removal estimates in 2004 from those in the 2006 NIR. The nature of Monte Carlo simulation also results in minor differences in emissions/removals between years.

Overall, this category results in a net emission to the atmosphere, although this is slowly decreasing over time, from 6,904 Gg in 1990 to 6,262 Gg in 2005. 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 (-50 and 53-122 Gg a^{-1} respectively).

1.3.5 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 2005. This category produced a net removal from the atmosphere in 1990 of -1,456 Gg, decreasing to -633 Gg in 1994, then rising to -1,306 Gg in 1998, before rapidly decreasing (and becoming a net emission in 2002) to a net emission of 619 Gg in 2004. The net emission in 2005 was 96 Gg. This variability is driven by forest planting and harvesting patterns in previous decades (see Thomson in the 2006 annual report). The current net emission from HWP results from the reduced levels of new planting during the 1940s, and we would expect this activity to become a net sink from 2006 onwards.

1.3.6 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 slightly smaller than that calculated in the 2004 inventory (2,882 Gg rather than 2,915 Gg). England is a net emitter between 1990 and 2005 (although on a downwards trend), while Scotland and Northern Ireland are net removers (with removals increasing 1990-2005). 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 in 1998 and continuing to a net removal of -2,056 Gg in 2005.

1.4 LUCF GHG Data on basis of IPCC 1996 Guidelines

The structure of this report and the 2007 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 1-26. An uncertainty of 20% was estimated for CH_4 and N_2O emissions from biomass burning after deforestation (categories 5C2 and 5E2). A full analysis of uncertainties is planned for future versions of the Inventory.

Table 1-26: 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 has now been asked to estimate LULUCF emissions/removals from the UK's Overseas Territories and Crown Dependencies who have joined the UK's instruments of ratification for the UNFCCC and the Kyoto Protocol. These Overseas Territories are Bermuda, the Cayman Islands, the Falkland Islands, Montserrat, the British Virgin Islands and Gibraltar. The Crown Dependencies are Jersey, Guernsey and the Isle of Man. A Masters student (Kate Ruddock, University of Edinburgh) is currently working on a project to assimilate data and construct inventories for these territories. This project will be completed by the end of August 2007 and the results will be reported in next year's annual report and National Inventory Report.

Table 1-27: 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
5	**NET**	**2882**	**2755**	**2251**	**1068**	**863**	**992**	**850**	**502**	**-53**	**-267**	**-449**	**-603**	**-1124**	**-1181**	**-1935**	**-2056**
5A	**Forest-Land**	**-12203**	**-12715**	**-13340**	**-13714**	**-14193**	**-13948**	**-13720**	**-13512**	**-13406**	**-13504**	**-13805**	**-14348**	**-15045**	**-15646**	**-16302**	**-15738**
5A1	*Forest-Land remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		*0*
5A2	*Land converted to Forest-*	*-12203*	*-12715*	*-13340*	*-13714*	*-14193*	*-13948*	*-13720*	*-13512*	*-13406*	*-13504*	*-13805*	*-14348*	*-15045*	*-15646*	*-16302*	*-15738*
5B	**Cropland**	**15836**	**15996**	**16001**	**15577**	**15631**	**15771**	**15803**	**15543**	**15428**	**15329**	**15339**	**15287**	**15313**	**15384**	**15316**	**15258**
5B1	*Cropland remaining Cropland*	*1802*	*1947*	*1938*	*1498*	*1535*	*1658*	*1672*	*1395*	*1262*	*1145*	*1136*	*1065*	*1072*	*1126*	*1039*	*964*
5B2	*Land converted to Cropland*	*14034*	*14048*	*14063*	*14079*	*14096*	*14113*	*14131*	*14148*	*14166*	*14185*	*14203*	*14222*	*14240*	*14258*	*14276*	*14294*
5B (liming)	*Liming of Cropland*	*792*	*974*	*1002*	*598*	*672*	*831*	*882*	*642*	*546*	*465*	*493*	*444*	*473*	*549*	*484*	*431*
5C	**Grassland**	**-6200**	**-6152**	**-6261**	**-6671**	**-6614**	**-6541**	**-6789**	**-6893**	**-7291**	**-7283**	**-7446**	**-7470**	**-7766**	**-7559**	**-7858**	**-7934**
5C1	*Grassland remaining*	*1028*	*1194*	*1198*	*915*	*1082*	*1256*	*1108*	*1125*	*827*	*854*	*728*	*747*	*564*	*872*	*685*	*692*
5C2	*Land converted to Grassland*	*-7228*	*-7346*	*-7458*	*-7585*	*-7695*	*-7797*	*-7897*	*-8017*	*-8118*	*-8136*	*-8174*	*-8216*	*-8330*	*-8431*	*-8543*	*-8627*
5C (liming)	*Liming of Grassland*	*638*	*798*	*808*	*532*	*598*	*698*	*633*	*705*	*512*	*422*	*301*	*281*	*265*	*369*	*330*	*288*
5D	**Wetland**	**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*
5D2	*Land converted to Wetland*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*	*IE*
5E	**Settlements**	**6904**	**6836**	**6770**	**6718**	**6671**	**6610**	**6578**	**6560**	**6521**	**6458**	**6413**	**6374**	**6327**	**6302**	**6291**	**6262**
5E1	*Settlements remaining*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5E2	*Land converted to Settlements*	*6904*	*6836*	*6770*	*6718*	*6671*	*6610*	*6578*	*6560*	*6521*	*6458*	*6413*	*6374*	*6327*	*6302*	*6291*	*6262*
5F	**Other-Land**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**0**
5F1	*Other-Land remaining Other-*	*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*
5G	**Other activities**	**-1456**	**-1210**	**-920**	**-842**	**-633**	**-900**	**-1021**	**-1197**	**-1306**	**-1268**	**-950**	**-445**	**47**	**337**		**619**
5G1	*Harvested Wood Products*	*-1456*	*-1210*	*-920*	*-842*	*-633*	*-900*	*-1021*	*-1197*	*-1306*	*-1268*	*-950*	*-445*	*47*	*337*	*619*	*96*
5B2, 5C2, 5E2	**Biomass burning Gg CH_4 a^{-1}**	*0.592*	*0.559*	*0.531*	*0.473*	*0.485*	*0.449*	*0.521*	*0.544*	*0.545*	*0.775*	*0.978*	*1.174*	*1.006*	*0.972*	*0.933*	*0.925*
5B2, 5C2, 5E2	**Biomass burning Gg N_2O a^{-1}**	*0.0041*	*0.0038*	*0.0037*	*0.0032*	*0.0033*	*0.0031*	*0.0036*	*0.0037*	*0.0037*	*0.0053*	*0.0067*	*0.0081*	*0.0069*	*0.0067*	*0.0064*	*0.0064*

1.7 References

Agricultural Industries Confederation (2006). *Fertiliser Statistics 2006 Report* www.agindustries.org.uk

Bellamy, P., Loveland, P.J., Bradley, R.I., Lark, R.M. and Kirk, G.J.D. (2005) Carbon losses from all soils across England and Wales. *Nature* **437**, 245-248.

BGS (2005). *United Kingdom Minerals Yearbook*. British Geological Survey, Natural Environment Research Council.

Bradley, R. I. (1997). Carbon loss from drained lowland fens. In: *Carbon Sequestration in Vegetation and Soils* (ed Cannell, M.G.R.). Department of Environment, London.

Bradley, R. I., Milne, R., Bell, J., *et al.* (2005). A soil carbon and land use database for the United Kingdom. *Soil Use and Management,* **21,** 363-369.

Burton, R. (1995). *Evaluating organic matter dynamics in cultivated organic topsoils – use of historical analytical data.* MAFF Contract to SSLRC No. LE0203 – 81/3830.

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

Cannell, M. G. R., Milne, R., Hargreaves, K. J., *et al.* (1999). National inventories of terrestrial carbon sources and sinks: The UK experience. *Climatic Change,* **42,** 505-530.

Cooper, A. and McCann, T. (2002). *Technical Report of the Northern Ireland Countryside Survey*. University of Ulster.

Cruickshank, M. and Tomlinson, R. (1997). Carbon loss from UK peatlands for fuel and horticulture. In: *Carbon Sequestration in Vegetation and Soils* (ed Cannell, M.G.R.). Department of Environment, London.

Cruickshank, M. and Tomlinson, R. (2000). Changes in soil carbon storage in Northern Ireland: estimated by the IPCC default and matrix methods. *Carbon Sequestration in Vegetation and Soils*. DETR Contract EPG 1/1/39, (ed Milne, R.). Department of Environment, London.

Cruickshank, M. M., Tomlinson, R. W., Devine, P. M. and Milne, R. (1998). Carbon in the vegetation and soils of Northern Ireland. *Biology and Environment-Proceedings of the Royal Irish Academy,* **98B,** 9-21.

Department of Communities and Local Government (2006). *Land use change in England to 2005*. Additional tables LUCS-21A. UK Government, London.

Dewar, R. C. and Cannell, M. G. R. (1992). Carbon Sequestration in the Trees, Products and Soils of Forest Plantations - an Analysis Using UK Examples. *Tree Physiology,* **11,** 49-71.

Edwards, P. N. and Christie, J. M. (1981). Yield models for forest management. *Forestry Commission Booklet*. 48. Forestry Commission, Edinburgh.

Forestry Commission (2002). National Inventory of Woodland and Trees. Forestry Commission http://www.forestry.gov.uk/forestry/hcou-54pg4d

Haines-Young, R. H., Barr, C. J., Black, H. I. J., *et al.* (2000). *Accounting for nature: assessing habitats in the UK countryside.* DETR Countryside Survey 2000, London.

Hargreaves, K. J., Milne, R. and Cannell, M. G. R. (2003). Carbon balance of afforested peatland in Scotland. *Forestry,* **76,** 299-317.

IPCC (1997a). *Greenhouse Gas Inventory Reference Manual.* IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (1997b). *Greenhouse Gas Inventory Reporting Instructions.* IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (1997c). *Greenhouse Gas Inventory Workbook.* IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry.* Institute for Global Environmental strategies (IGES) for the Intergovernmental Panel on Climate Change, Kanagawa, Japan.

Levy, P. E. and Milne, R. (2004). Estimation of deforestation rates in Great Britain. *Forestry,* **77,** 9-16.

Milne, R. and Brown, T. A. (1997). Carbon in the vegetation and soils of Great Britain. *Journal of Environmental Management,* **49,** 413-433.

Milne, R. and Brown, T. A. W. (1999). Methods and data for Land Use Change and Forestry Sector in the 1997 IPCC Greenhouse Gas Inventory. In: *Carbon Sequestration in Vegetation and Soils* (ed Milne, R.).

Milne, R., Brown, T. A. W. and Murray, T. D. (1998). The effect of geographical variation in planting rate on the uptake of carbon by new forests of Great Britain. *Forestry,* **71,** 298-309.

MLC (1986). *Monitoring Landscape Change.* Report prepared by Hunting Surveys & Consultants Ltd for Department of the Environment and the Countryside Commission.

Pineiro, G., Oesterheld, M., Batista, W.B. and Paruelo, J. (2006) Opposite changes of whole-soil vs. pools C : N ratios: a case of Simpson's paradox with implications on nitrogen cycling. *Global Change Biology* **12** (5), 804–809.

Skiba. U. (2005). The influence of land use change from and to forestry on the emissions of nitrous oxide and methane. (http://www.edinburgh.ceh.ac.uk/ukcarbon/docs/Defra_Report_2005_Section3.pdf)

Skiba, U., Di Marco, C., Dragositz, U., *et al.* (2005). Quantification and validation of the total annual UK nitrous oxide budget. *Final report to NERC - GANE*. Centre for Ecology and Hydrology.

Smith, P., Smith, J.U., Flynn, H., Killham, K., Rangel-Castro, I., Foereid, B., Aitkenhead, M., Chapman, S., Towers, W., Bell, J., Lumsdon, D., Milne, R., Thomson, A., Simmons, I., Skiba, U., Reynolds, B., Evans, C., Frogbrook, Z., Bradley, I., Whitmore, A., Falloon, P. (2007). *ECOSSE: Estimating Carbon in Organic Soils - Sequestration and Emissions. Final Report*. SEERAD Report. ISBN 978 0 7559 1498 2. 166pp.

Sylvester-Bradley, R., Lunn, G., Foulkes, J., *et al.* (2002). Management strategies for high yields of cereals and oilseed rape. In *HGCA R&D Conference - Agronomic Intelligence: The basis for profitable production*, pp. 8.1-8.17. Home-Grown Cereals Authority.

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

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2.1 Introduction

CEH produced a voluntary submission of CRF tables for activities under the Kyoto Protocol (Articles 3.3 and 3.4) for submission to the UN 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). The UK has opted to use entire commitment period accounting (2008-2012) for activities under Article 3.3 and 3.4, reporting in 2014.

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 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 (the national forestry agency) 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. 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). Therefore, Afforestation and Reforestation under Article 3.3 can be considered together. 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 uncertainty is associated with deforestation as compared with afforestation.

2.3 Land-related information

2.3.1 Spatial assessment unit used

The spatial assessment units used for the voluntary submission of the Kyoto Protocol CRF tables in April 2007 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. In this draft method, 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 and the Northern Irish grid projection for Northern Ireland cells).

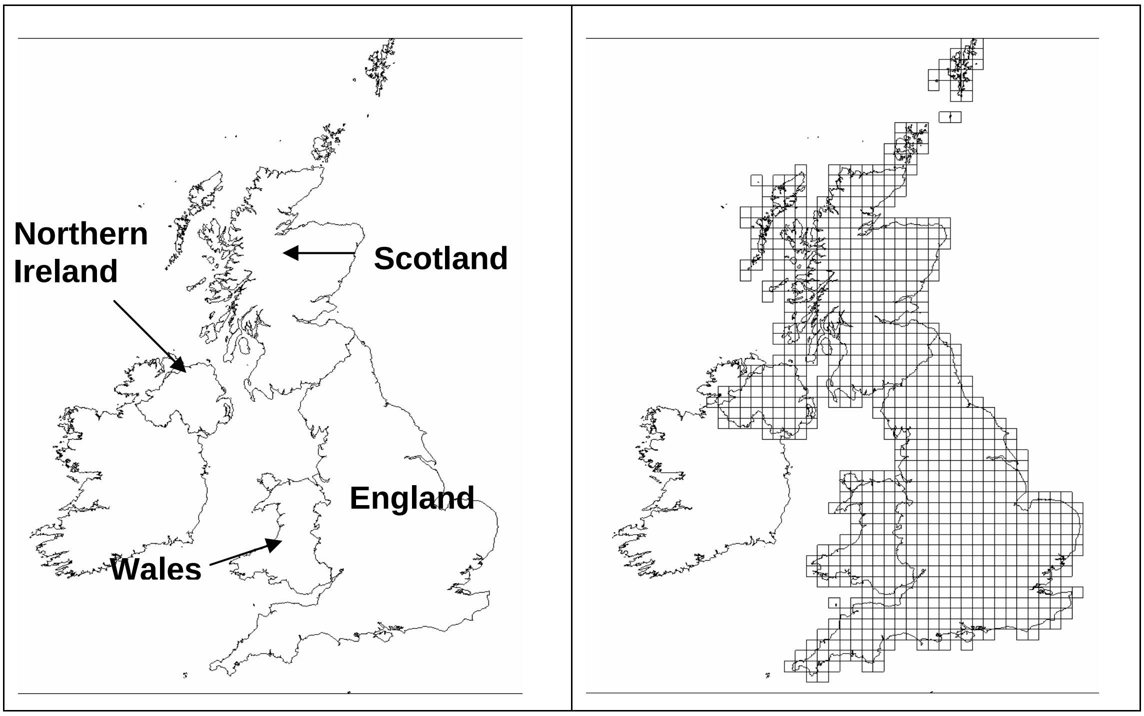

Figure 2-1: Spatial units used for reporting Kyoto protocol LULUCF activities: (left) the four countries of the UK, (right) 20 x 20km grid cells covering the UK.

2.3.2 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 2-3). 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 2-1. 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. The relationship between data sources and the proposed land transition matrix at the 20km grid scale is shown in
Table2 -2.

Table 2-1: 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.

Table2 -2: 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.

Table 2-3: 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.

2.4 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 and in harvested wood products. 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. It should be possible to modify the C-Flow model so that it produces estimates for these carbon pools for future reporting.

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.

Emissions from fertilization and liming of forest land are not currently estimated. Applications of fertilizer and lime since 1990 are estimated by the Forestry Commission to be negligible due to economic factors. A methodology for estimating emissions of N_2O from the spreading of sewage sludge on forest land is under consideration (see Chapter 6). Emissions of N_2O from areas in Forest Management due to the drainage of soils are not currently estimated, although a methodology is under development (also in Chapter 6).

At present, emissions of greenhouse gases due to biomass burning are only estimated for Deforestation. Hopefully, biomass burning will diminish as the use of woodfuel as a source of bioenergy becomes more commonplace. Damage to existing forests by accidental fires (fire resulting from natural causes is very rare) is not a serious problem in the UK (Forestry Commission, 2002). Data on the occurrence of fires are available for state-owned woodland to 2004, but not for privately-owned woodland. The Forestry Commission is apparently investigating the possibility of enhanced reporting of woodland fires from 2007-2008 as one of its indicators of sustainable forestry. It can be assumed that wildfires will not result in permanent deforestation. This area will be kept under review, and a methodology for emission estimation will be developed once improved data becomes available.

2.5 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.

Under the proposed method, the grant-aided woodland database and the Forestry Commission management database will be used to estimate areas of Article 3.3 activities. These data have currently been provided for 1995 to the latest year available (2006) and will be updated annually. Preliminary comparisons have shown good agreement between these data sources and the national planting statistics. It may be possible to extend the FC management database back to 1990 but the grant-aided database is incomplete before 1995. The time-series gap between 1990 and 1995 will be filled by taking the national planting statistics and distributing them between the 20km grid cells in proportion with the distribution of post-1990 planting age woodland in the NIWT (this work has been done – see Chapter 7).

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.

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 been using the scenarios described in Chapter 4. These projections are presented for Mid, Low and High emission scenarios for the UK, England, Scotland, Wales and Northern Ireland in Appendix 4 and in Figure 2-2.

2.6 Article 3.4

Countries could elect to use net sinks within Forest Management, Cropland Management, Grassland Management and/or Revegetation 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 (Revegetation 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 2-3. Removals exceed the cap for all years except 2020.

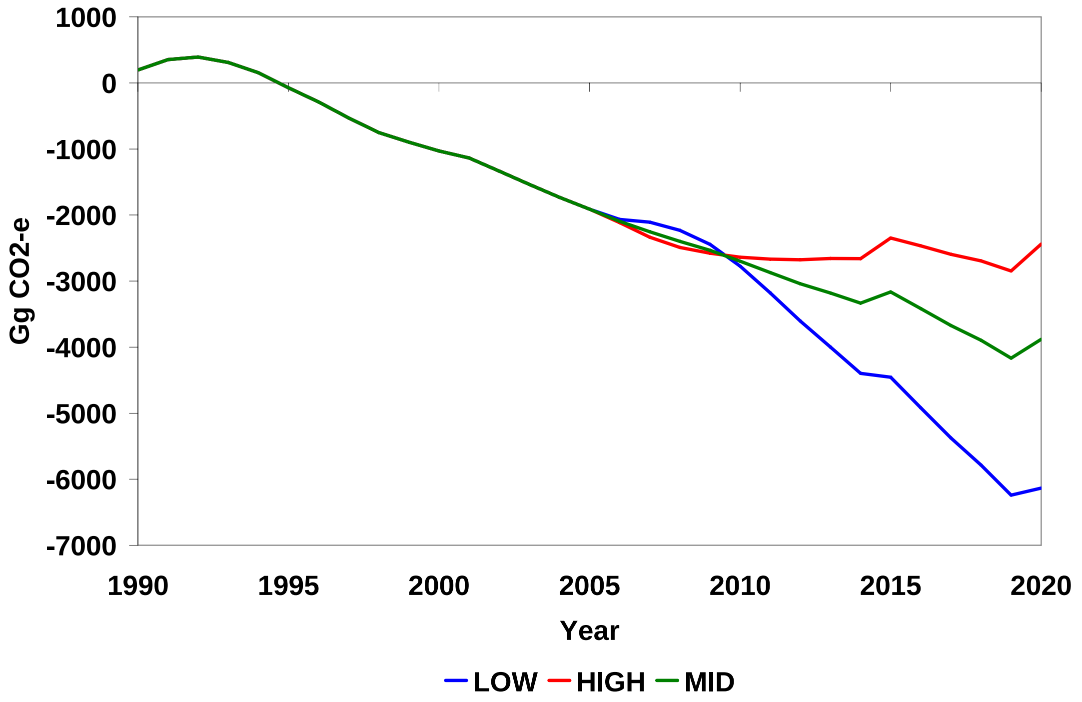

Figure 2-2: Kyoto Protocol Article 3.3: Net flux associated with post-1990 ARD for the Mid, Low and High emission scenarios

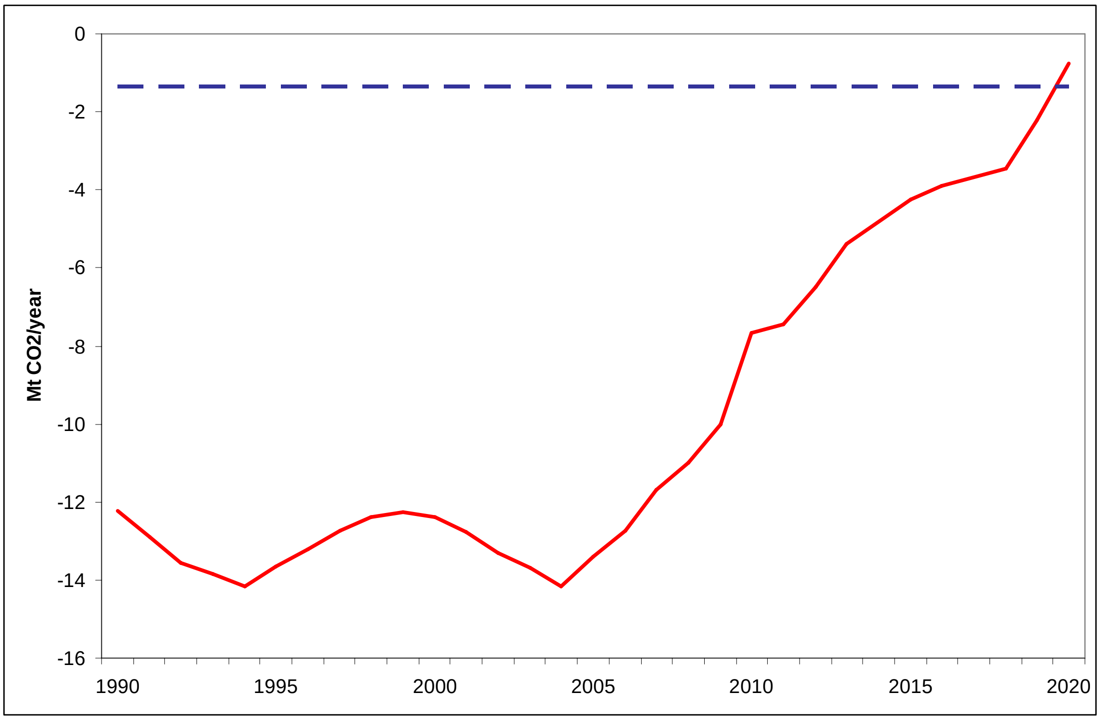

Figure 2-3: Kyoto Protocol Article 3.4: Removals and emissions associated with Forest Management for the MID scenario. The UK cap of -0.37 MtC/year (-1.36 Mt CO_2 eq.) is shown by the broken line.

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 2006 was 1233 kha (Forestry Commission, 2006). 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).

2.7 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 2005 inventory is 332 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.

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 afforestation and deforestation activities (under Article 3.3 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 2006 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. "Central" (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. For simplicity detailed information on the emissions and removals is only supplied on the basis of the reporting format defined by the IPCC LULUCF Good Practice Guidance. A summary table of the net UK flux under the different emission scenarios is shown in Table 4-1.

Table 4-1: Inventory (1990 to 2005) and projected (to 2020) Emissions and Removals data (GgCO_2/year). (-ve sign indicates Removal)

Year	Net (LOW)	Net (MID)	Net (HIGH)
1990	2882	2882	2882
1995	992	992	992
2000	-449	-449	-449
2005	-2056	-2056	-2056
2010	-3294	-1554	207
2015	-3850	488	4338
2020	-4460	2223	8138

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 are also plotted in Figure 4-1. 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 4-2. Projections to 2020 of net fluxes of carbon dioxide from the atmosphere in England, Scotland, Wales and N. Ireland are plotted in Figure 4-3. Projections of net fluxes for Forest Land, Cropland, Grassland and Settlements for each scenario for the individual Devolved Administrations are plotted in Figure 4-4, Figure 4-5, Figure 4-6 and Figure 4-7.

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

Scenario assumption: England			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Forestry	UK Total of 30 kha/yr from 2006 in proportion to 2005 planting	Conifer planting from 2006 assumed to be as in 2005. Broadleaf planting from 2006 assumed to be as in 2005.	Conifer planting from 2006 assumed to be 0 ha/yr. Broadleaf planting from 2006 assumed to be 0 ha/yr.
Deforestation	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
Land Use Change (Soils)	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but minimum values from Monte Carlo simulation with range of areas	Annual area land use change for 2006 to 2020 assumed to be same as annual rate of change for 1990 to 2005. – mean values from Monte Carlo simulation starting from 2005	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but maximum values from Monte Carlo simulation with range of areas
Peat extraction	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
Liming	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	Flux changes from 2005 at modelled rate of change for 1990 to 2000	Flux changes from 2005 at modelled rate of change	Flux changes from 2005 value at modelled rate of change for 2010 to 2020
Non-forest biomass	Flux remains at 2005 value	Flux remains at 2005 value	Flux remains at 2005 value

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

Scenario assumption: Scotland			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Afforestation	UK Total of 30 kha/yr from 2006 in proportion to 2005 planting	Conifer planting from 2006 assumed to be as in 2005. Broadleaf planting from 2006 assumed to be as in 2005.	Conifer planting from 2006 assumed to be 0 ha/yr. Broadleaf planting from 2006 assumed to be 0 ha/yr.
Deforestation	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
Land Use Change (Soils)	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but minimum values from Monte Carlo simulation with range of areas	Annual area land use change for 2006 to 2020 assumed to be same as annual rate of change for 1990 to 2005. – mean values from Monte Carlo simulation starting from 2005	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but maximum values from Monte Carlo simulation with range of areas
Peat extraction	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 Scottish data	As MID but trend adjusted to upper value (95% C.L) of 1990 to 2005 trend
Liming	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	NA	NA	NA
Non-forest biomass	Flux remains at 2005 value	Flux remains at 2005 value	Flux remains at 2005 value

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

Scenario assumption: Wales			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Forestry	UK Total of 30 kha/yr from 2006 in proportion to 2005 planting	Conifer planting from 2006 assumed to be as in 2005. Broadleaf planting from 2006 assumed to be as in 2005.	Conifer planting from 2006 assumed to be 0 ha/yr. Broadleaf planting from 2006 assumed to be 0 ha/yr.
Deforestation	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
Land Use Change (Soils)	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but minimum values from Monte Carlo simulation with range of areas	Annual area land use change for 2006 to 2020 assumed to be same as annual rate of change for 1990 to 2005. – mean values from Monte Carlo simulation starting from 2005	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but maximum values from Monte Carlo simulation with range of areas
Peat extraction	Flux zero	Flux zero	Flux zero
Liming	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	NA	NA	NA
Non-forest biomass	Flux remains at 2005 value	Flux remains at 2005 value	Flux remains at 2005 value

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

Scenario assumption: Northern Ireland			
Category	**LOW Emission**	**MID Emission**	**HIGH Emission**
Forestry	UK Total of 30 kha/yr from 2006 in proportion to 2005 planting	Conifer planting from 2006 assumed to be as in 2005. Broadleaf planting from 2006 assumed to be as in 2005.	Conifer planting from 2006 assumed to be 0 ha/yr. Broadleaf planting from 2006 assumed to be 0 ha/yr.
Deforestation	NA	NA	NA
Land Use Change (Soils)	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but minimum values from Monte Carlo simulation with range of areas	Annual area land use change for 2006 to 2020 assumed to be same as annual rate of change for 1990 to 2005. – mean values from Monte Carlo simulation starting from 2005	Annual area land use change for 2006 to 2020 based on annual rate of change for 1990 to 2005. but maximum values from Monte Carlo simulation with range of areas
Peat extraction	Flux remains at 2005 value	Flux remains at 2005 value	Flux remains at 2005 value
Liming	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	NA	NA	NA
Non-forest biomass	Flux remains at 2005 value	Flux remains at 2005 value	Flux remains at 2005 value

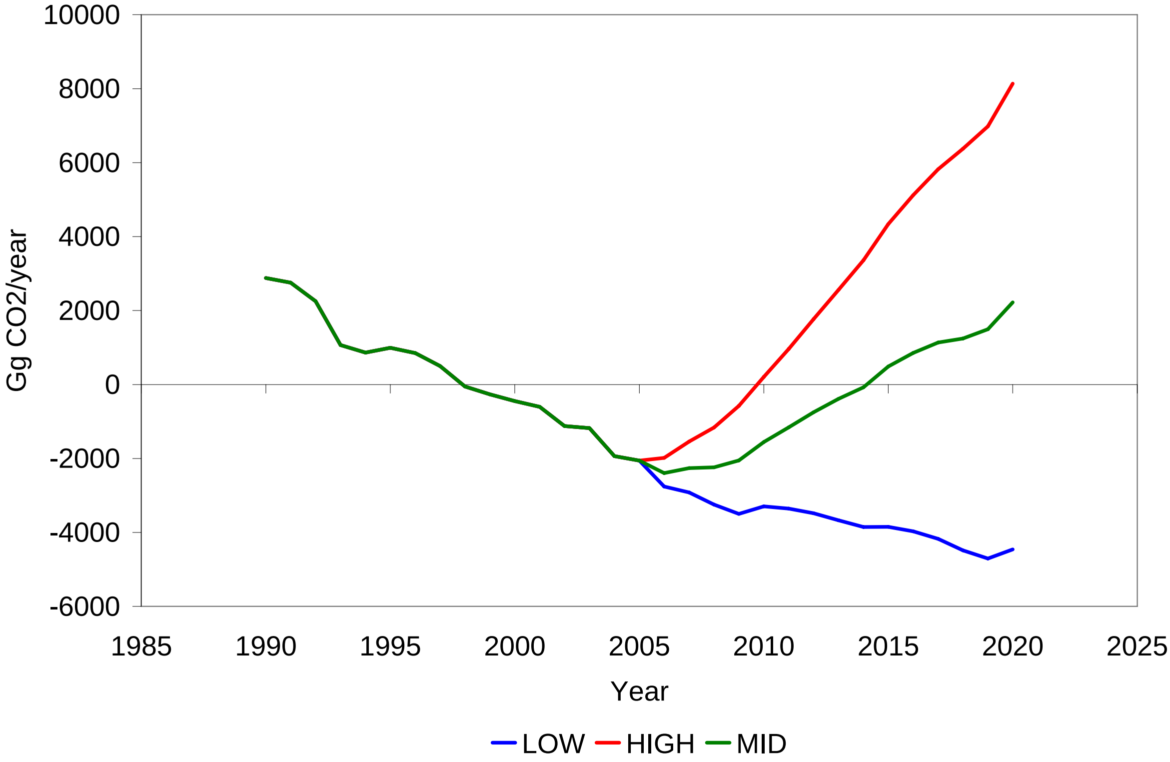

Figure 4-1: Projections to 2020 of Net Emissions and Removals of carbon dioxide from the atmosphere in the United Kingdom by Land Use, Land Use Change and Forestry for 3 future emissions scenarios

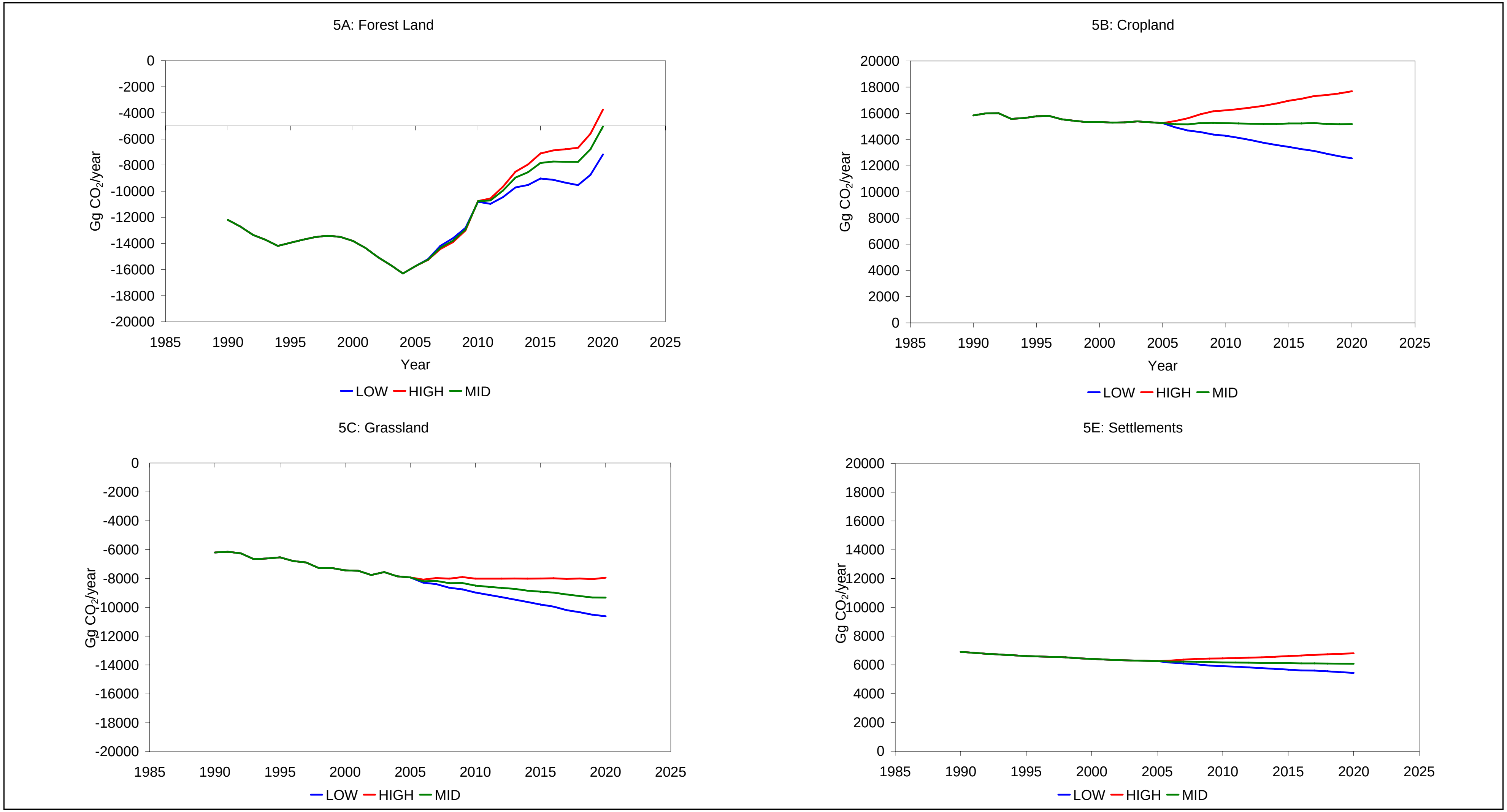

Figure 4-2: Projections to 2020 of Forest Land, Cropland, Grassland and Settlements (Urban) Net Emissions of carbon dioxide from the atmosphere in the United Kingdom by Land Use, Land Use Change and Forestry for 3 future emissions scenarios.

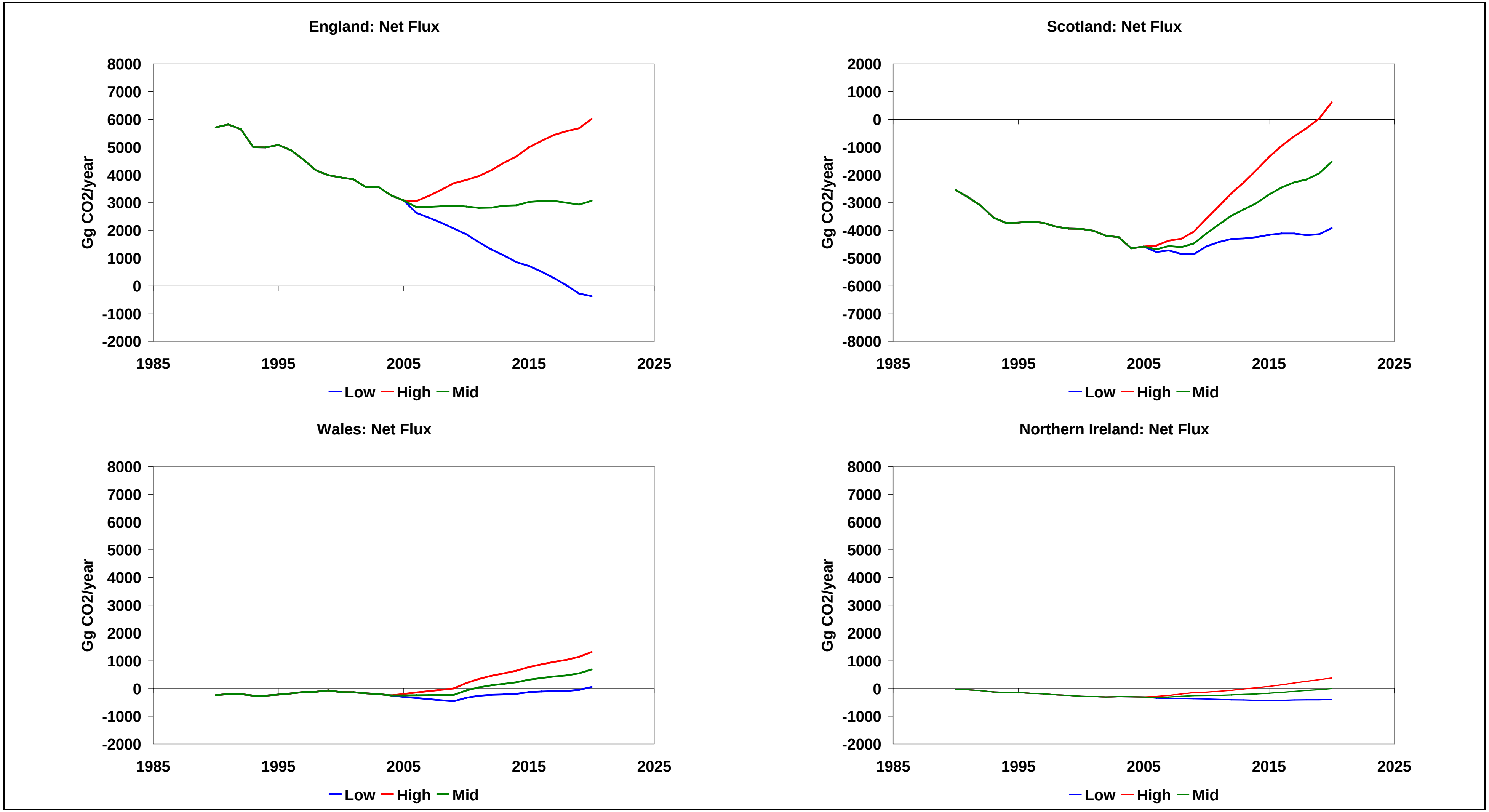

Figure 4-3: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by Land Use, Land Use Change and Forestry for 3 future emissions scenarios.

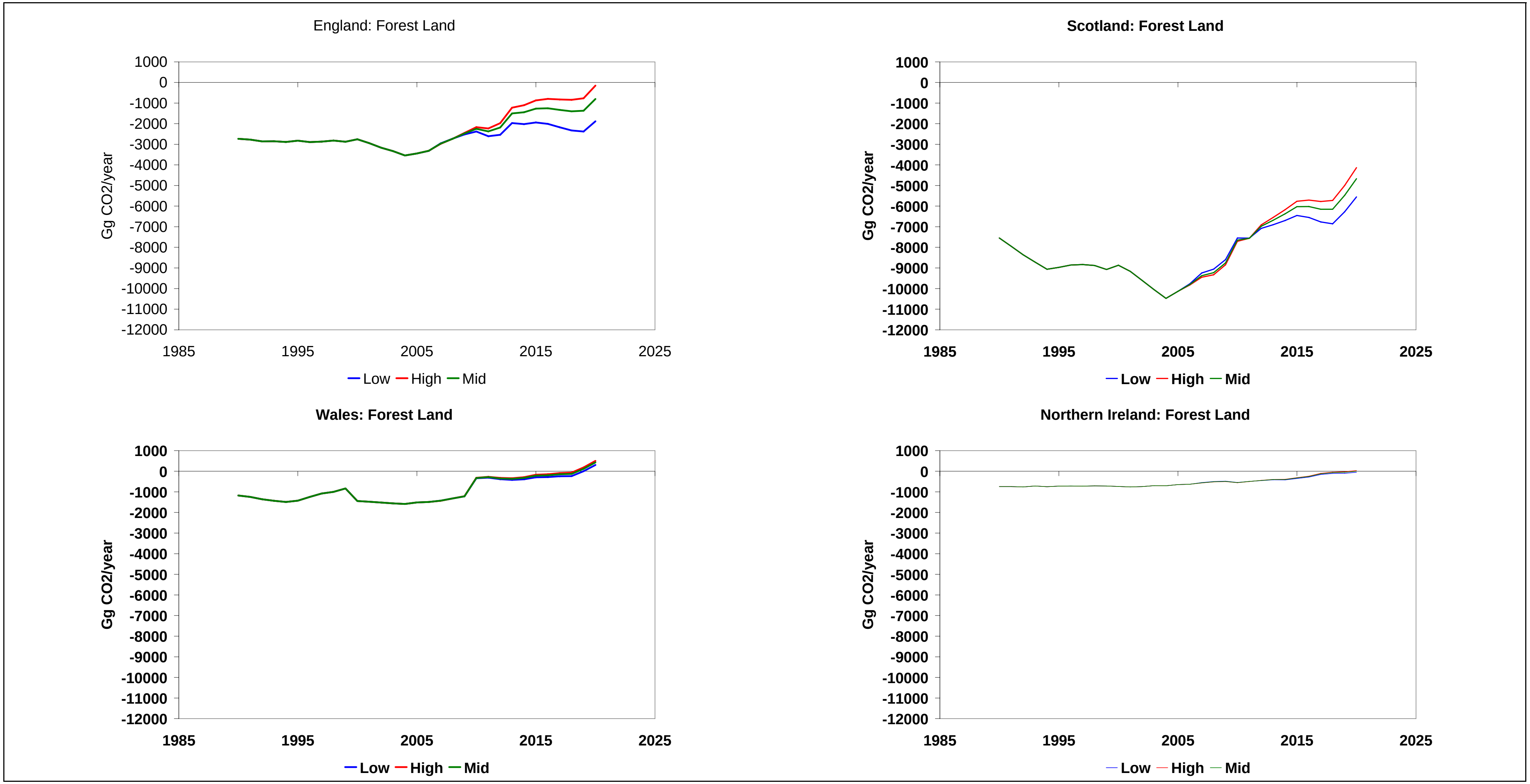

Figure 4-4: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Forest Land Category (5A) for 3 future emissions scenarios.

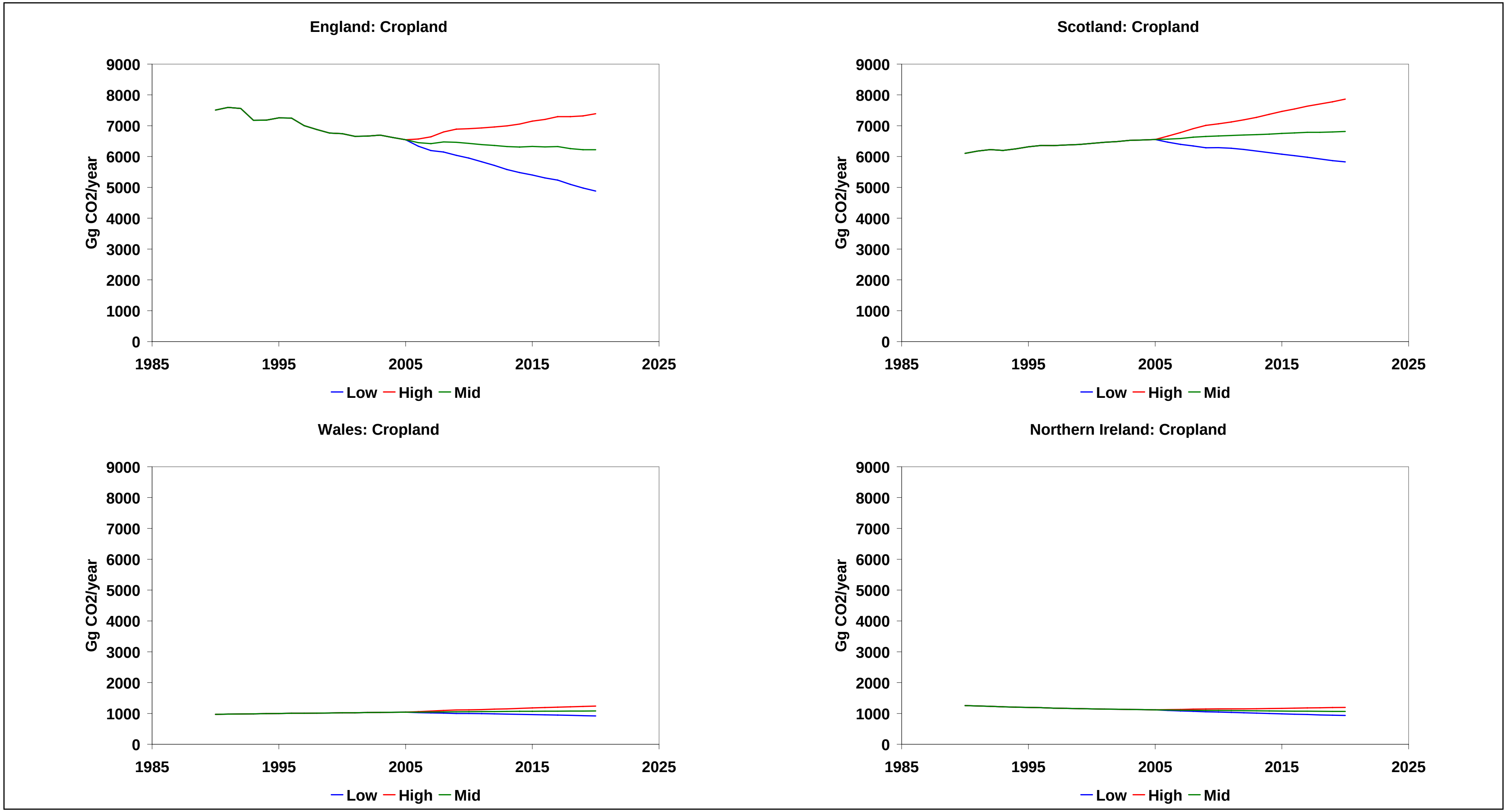

Figure 4-5: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Cropland Category (5B) for 3 future emissions scenarios

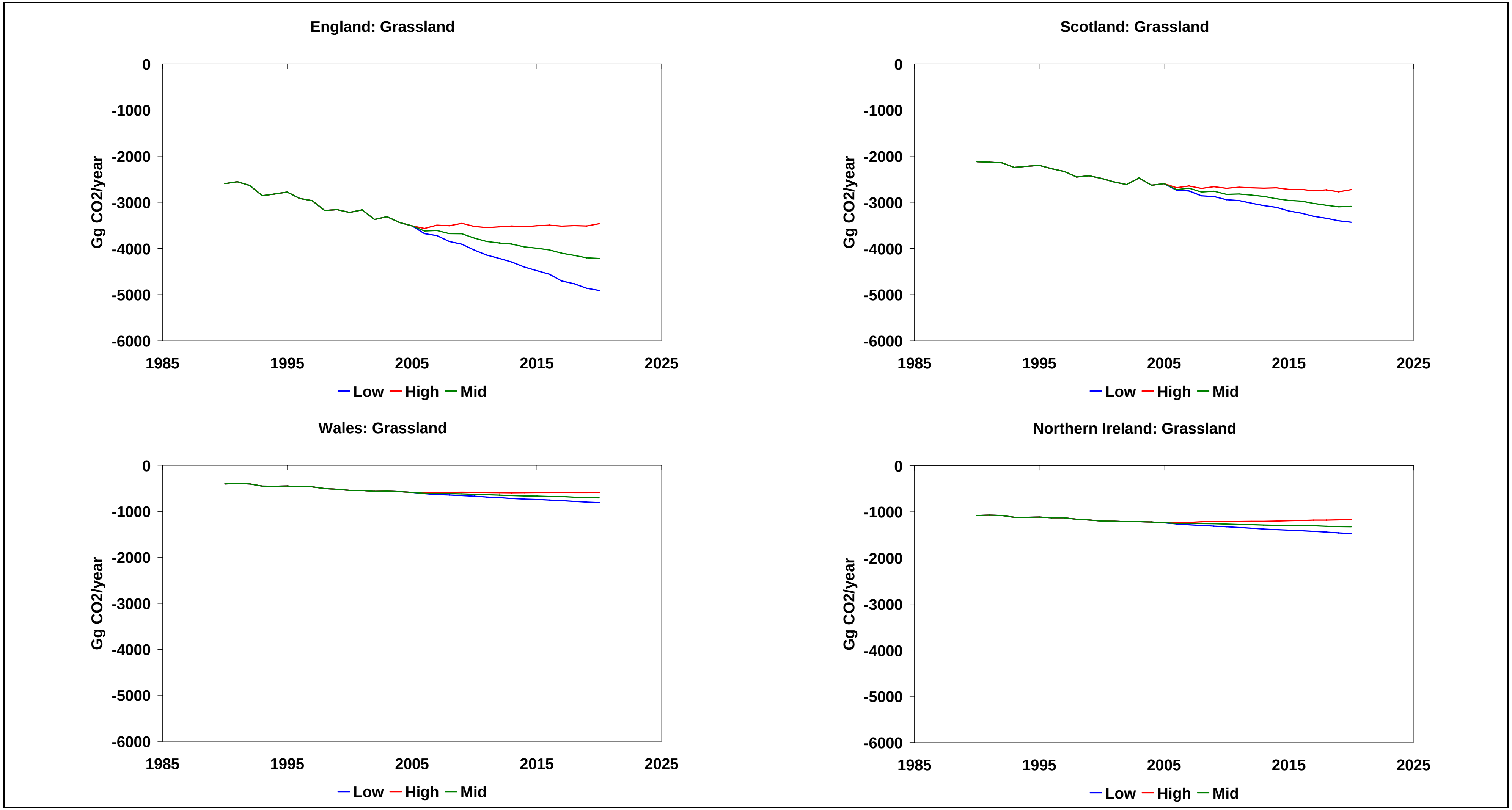

Figure 4-6: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Grassland Category (5C) for 3 future emissions scenarios

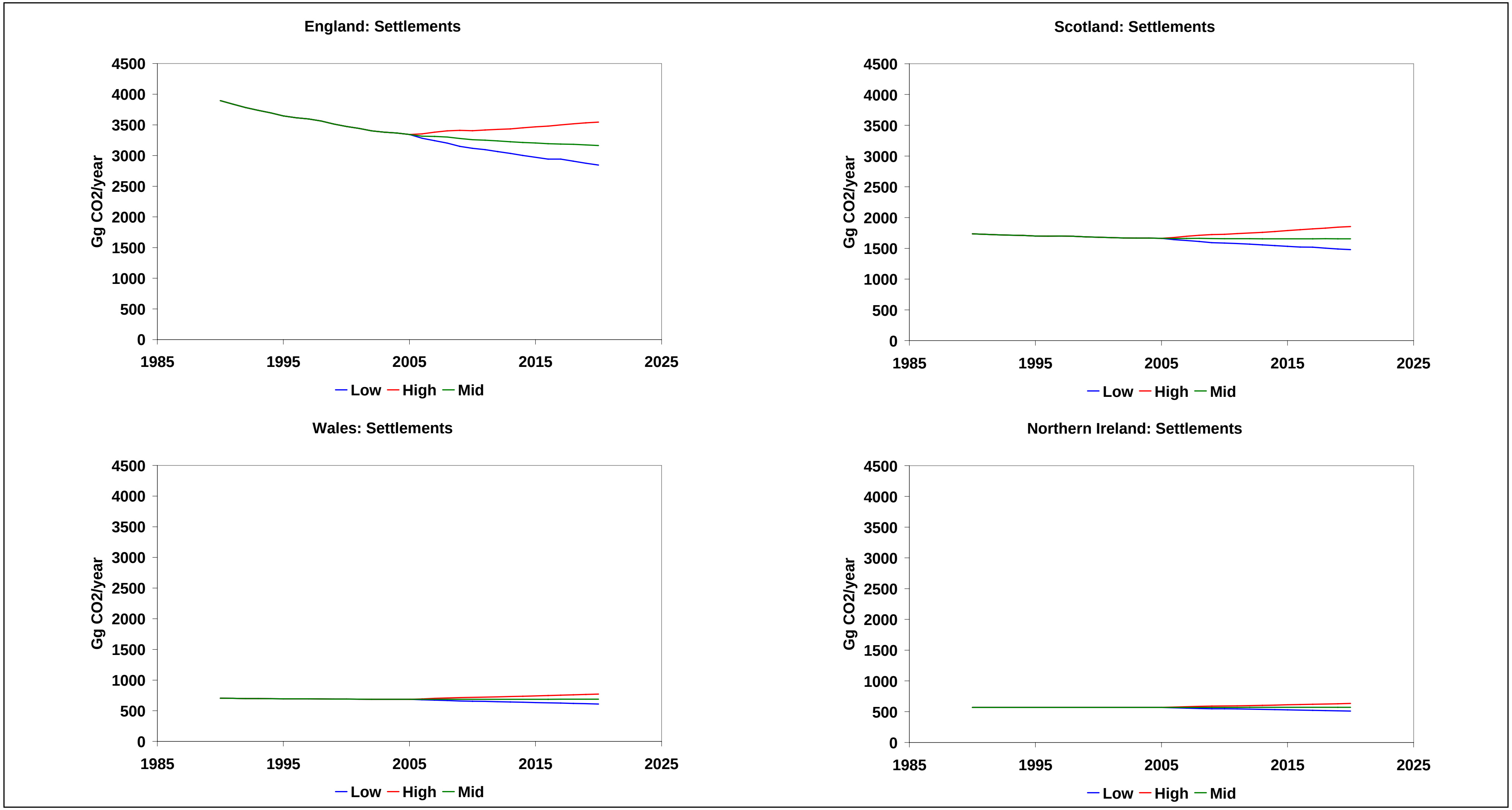

Figure 4-7: Projections to 2020 of Net Emissions of carbon dioxide from the atmosphere in England, Scotland, Wales and Northern Ireland by the Settlements (Urban) Category (5E) for 3 future emissions scenarios

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

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The current system of spreadsheets has been streamlined and made more transparent with additional comments embedded with the data. Some Matlab scripts have been written to accurately compile the key data for submission. Work on the proposed ‘report generator’ software was postponed due to changes in the latest release of the CRF Reporter software making the original design less useful. A new specification has been designed and will be completed in August.

The inventory manual, for internal CEH use, has been converted to a web-based ‘wiki’ making it more accessible to staff. The documentation and workflow procedures can be updated more efficiently by anyone working on the project, with new information immediately available to all colleagues. Task and issue management software is being considered for use in Year 2.

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 come from 3 types of activities: (i) biomass burning as part of deforestation producing CH_4 and N_2O emissions, (ii) application of fertilisers to forests producing N_2O and (iii) disturbance of soils due to some types of land use change producing N_2O associated with CO_2 emissions. Emissions by biomass burning are discussed elsewhere (in the Grassland and Settlements sections of Chapter 1). Emissions of N_2O from fertilization and soil disturbance (drainage) are discussed below.

6.1 N fertilization of forests

Direct N_2O emissions from N fertilization of forests have previously not been estimated as they were assessed as small in the UK. This assessment has been re-examined but due to the incompleteness of the time series the data has not been included in the 1990-2005 CRF tables. Fertiliser containing N has not been applied to existing forests (5.A.1) in the UK since about 2000, and for 1990 – 2000 applications of 100 kg N/ha/yr were assumed to be typical. The area receiving applications of N between 1990 and 2000 are not readily available. Such data are presently being sought from the Forestry Commission and other organisations. In 2005 two forests in Scotland (Dornoch (242 ha) and Inverness (35 ha)) were experimentally fertilised with mineral N at a rate of 350 kg N/ha. Therefore a total 97 tonnes of N were applied which, using the default IPCC N_2O emission factor of 1.25%, resulted in an emission of 1.2125 tonnes N_2O-N equivalent to 1.905 tonnes N_2O, or 0.591 Gg CO_2 equivalent.

Sewage sludge has been used in Scotland in land restoration projects (5.A.2). For example in 2005 sewage sludge was used on derelict land with little or no *in situ* topsoil, where it was intended to establish new forest. Sewage sludge was also applied to harvested forest sites where it was intended to replant trees but to a much lesser extent. In 2006 the amount of sludge used for such purposes has been greatly reduced. Further investigation of similar projects in earlier years is under way. The area of restoration in 2005 is not recorded, but 48,400 t of dry sewage sludge were used. Assuming 1 t of dry sludge contains 0.03 t N, 1452 tonnes of N would have been applied. Using the default N_2O emission factor of 1.25% gives an emission of 18.15 tonnes N_2O-N equivalent to 28.52 tonnes N_2O, or 8.841.Gg CO_2 equivalent.

Together the use of fertilisers and sewage sludge on forests in 2005 is therefore estimated to have caused emission of 30.425 tonnes N_2O. Although the GWP of N_2O is 310, giving an equivalent CO_2 emission of 9.4 Gg, this is very small compared to other emissions and removals in the LULUCF Sector.

6.2 Emissions of N_2O as a result of disturbance due to land use change

In the UK drainage of some form has occurred when new forests are planted. The method recommended in the LULUCF GPG for calculating N_2O emissions due to land use change is to use the CO_2 emission due to a specific change and then use the

C:N ratio for the soils being disturbed to estimate the N lost due to the mineralisation of organic matter. The default emission factor for the N_2O pathway (1.25%) is then used to calculate the emitted flux of N_2O-N. Table 6-1 shows the emissions for the period from 1990 to 2005 adopting this approach with a C:N ratio of 15:1 for all land.

Table 6-1: Emissions of N_2O in the UK due to disturbance of soils after land use change estimated by the method of the LULUCF GPG

	Forest Land to Grassland	**Forest Land to Cropland**	**Forest Land to Settlement**	**Grassland to Cropland**	**Grassland to Settlement**	**Cropland to Settlement**	**ALL LUC**
	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O	Gg N_2O
1990	0.035	0.004	0.026	4.995	2.019	0.401	7.482
1991	0.035	0.004	0.029	5.001	2.008	0.390	7.466
1992	0.035	0.004	0.031	5.006	1.997	0.378	7.452
1993	0.034	0.004	0.035	5.012	1.986	0.368	7.439
1994	0.034	0.003	0.037	5.018	1.977	0.358	7.428
1995	0.036	0.003	0.038	5.024	1.968	0.349	7.419
1996	0.037	0.003	0.039	5.031	1.960	0.340	7.410
1997	0.034	0.003	0.044	5.037	1.953	0.332	7.403
1998	0.034	0.003	0.046	5.044	1.946	0.324	7.396
1999	0.045	0.003	0.037	5.050	1.939	0.317	7.391
2000	0.050	0.002	0.033	5.057	1.933	0.310	7.386
2001	0.054	0.002	0.031	5.064	1.928	0.303	7.382
2002	0.056	0.002	0.031	5.071	1.923	0.297	7.379
2003	0.056	0.002	0.032	5.077	1.918	0.292	7.377
2004	0.054	0.002	0.035	5.084	1.913	0.286	7.375
2005	0.056	0.002	0.035	5.090	1.909	0.281	7.373

The 1990 emission rate for all land use change from Table 6-1 is equivalent to an emission of 2319 Gg CO_2 (using a GWP of 310), which is similar to the net uptake of CO_2 equivalents by all other activities in the UK LULUCF Sector. It is therefore of considerable importance that the methodology used is scientifically sound. On further investigation this does not appear to be the case. The LULUCF GPG methodology relies on estimating gross nitrogen loss from a gross carbon loss and a C:N ratio, but several factors suggest that this approach does not lead to reliable values. There are few measurements of C:N ratios for different land use and for different environmental conditions, making it difficult to generalise values for a whole country. More importantly, understanding of the mechanisms that cause C:N ratios to vary with different land management is weak, particularly in relation to how changes in the C:N ratio of different pools in the soil affect the gross C:N ratio. For example Pineiro *et al.* (2006) show that it is possible to obtain gross N-mineralisation changes of opposite sign depending on whether changes in whole-soil or individual pool C:N ratios are considered in a model of the effect of grazing on soil. It would therefore seem prudent to await an alternative approach to estimating N_2O emissions due to land use change before including any data in the inventory. Research is being undertaken to measure change in stocks of soil carbon and nitrogen due to ploughing of an upland grassland (Work Package 2.6), which should contribute to greater understanding in this area.

6.3 Emissions of N_2O from disturbance of soils by afforestation

The methodology used to estimate CO_2 removals and emissions due to the establishment of forests is described in the Forest Land section of Chapter 1. Included in these estimates are emissions relating to the loss of carbon (as CO_2) as a result of disturbance of the pre-existing soil. The pattern of immediate and delayed emissions is taken to be that measured at a peatland site but the amplitude of the loss is reduced for afforestation in other locations. It could therefore be assumed that nitrogen in the soil will be lost with the carbon in proportion to the C:N ratio as suggested by the LULUCF GPG for other types of land use change that cause carbon mineralization. Area afforestation rates in the UK have been disaggregated into those for planting of conifers on organic and non-organic soils and for broadleaves (which normally occurs on mineral soils). We investigated this approach for calculating nitrogen loss by assuming that organic soils (conifer planting) had a C:N ratio of 30:1 but non-organic soils used for planting had a C:N ratio of 15:1. The N_2O emission factor was taken to be the default value of 1.25%. Emissions of N_2O estimates by this approach are presented in Table 6-2. All forests planted since 1921 are included in this approach but no explicit account of the degree of drainage in these forests is included. The fluxes measured by Hargreaves *et al*. (2003), which are the basis for the method of estimating CO_2 emissions due to planting, were ~ 4 tC/ha/yr initially and estimated to fall to ~0.3 tC/ha/yr in the long term. Assuming a C:N ratio of 30:1 for peat the resulting N_2O emissions would be of the same order of magnitude as those suggested as Tier 1 Defaults in the LULUCF GPG. These emission rates are not as large as those found for Grassland conversion but the criticisms of using gross C:N ratios to obtain N loss also apply. A further consideration of methods will therefore be needed before data can be included in the inventory.

Table 6-2: Emissions of N_2O due to afforestation since 1921 in the UK using an adaptation of the LULUCF GPG approach for general land use change.

	Conifer organic	**Conifer mineral**	**Broadleaf (mineral)**
	Gg N_2O	Gg N_2O	Gg N_2O
1990	0.154	0.885	0.097
1991	0.147	0.849	0.117
1992	0.139	0.812	0.135
1993	0.131	0.776	0.155
1994	0.123	0.737	0.183
1995	0.116	0.704	0.211
1996	0.111	0.678	0.230
1997	0.106	0.654	0.244
1998	0.101	0.633	0.260
1999	0.097	0.614	0.274
2000	0.093	0.597	0.288
2001	0.090	0.579	0.311
2002	0.085	0.559	0.327
2003	0.082	0.540	0.328
2004	0.078	0.523	0.326
2005	0.075	0.506	0.325

6.4 References

Hargreaves, K. J., Milne, R. and Cannell, M. G. R. (2003). Carbon balance of afforested peatland in Scotland. *Forestry,* **76,** 299-317

Pineiro, G., Oesterheld, M., Batista, W.B. and Paruelo, J. (2006) Opposite changes of whole-soil vs. pools C : N ratios: a case of Simpson's paradox with implications on nitrogen cycling. *Global Change Biology* **12** (5), 804–809.

Skiba. U. (2005). The influence of land use change from and to forestry on the emissions of nitrous oxide and methane. (http://www.edinburgh.ceh.ac.uk/ukcarbon/docs/Defra_Report_2005_Section3.pdf)

Skiba, U., Di Marco, C., Dragositz, U., *et al.* (2005). Quantification and validation of the total annual UK nitrous oxide budget. *Final report to NERC - GANE*. Centre for Ecology and Hydrology.

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

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7.1 Introduction

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. CEH's work in the first phase of the project has concentrated on the investigation of spatial variation in planting patterns under different ownership types since 1990. This has particular relevance for the estimation of carbon fluxes from Afforestation under Article 3.3 of the Kyoto Protocol. For this work package Forest Research have developed draft scenarios of forest management in the devolved regions. These include taking account of revised assumptions abut restocking of existing forests to diversify composition, improved estimates of yield class distribution by species and better representation of new forest management regimes, notably "Low Impact Silvicultural Systems".

7.2 Data sources for spatial modelling work

The activity data for estimating afforestation fluxes up to now have been annual planting statistics for each country. More detailed data sources have now become available from the various forestry agencies and can be combined together to construct forest planting time series from 1990 to 2005 at the 20km grid cell scale. Data is reported by planting year, which runs from 1st April to 31st March of the following year, i.e. a planting year of 1995 corresponds to the period 1st April 1994 to 31st March 1995.

7.2.1 Forestry Commission Sub-Compartment Database

The Forestry Commission Sub-Compartment Database (FC SCDB) contains management information (species, stocking, age etc.) for each forest compartment in the public forest estate. The Forestry Commission provided an extract of this database (actually two separate databases) with all compartment records with a planting date of 1995 onwards, identified by the 20km grid cell reference (the SQUID). The relevant attributes for this work package are the species, the planting year, the yield class, the area of the forest compartment and the rotation (whether new planting or restocking).

7.2.2 Woodland Grant Scheme

The Forestry Commission Grants and Licences section supplied annual data on planting funded by the Woodland Grant Scheme (England, Scotland and Wales 1995-2006) and the Scottish Forestry Grant Scheme (Scotland only 2003-2006). These schemes cover new planting and restocking in private woodland funded by the Forestry Commission. Grants are only paid once planting has been completed. Data is split by coniferous and broadleaf planting (no species split available) and by NUTS4 administrative region (local authority regions).

The Northern Ireland Forest Service supplied figures for areas planted under the Northern Ireland Woodland Grant Scheme since 1996. This data on private woodland planting has only recently been transferred into GIS and there are still some teething problems with the data set. Data was split by the old county regions (Antrim, Armagh, Down, Fermanagh, Derry and Tyrone) but was not split by conifer/broadleaf planting. Data split by NUTS4 administrative region and conifer/broadleaf is being sought but has not yet become available.

7.2.3 National Inventory of Woodland and Trees

The National Inventory of Woodland and Trees (NIWT) is the most recent forest survey undertaken in Great Britain. The NIWT consists of two surveys: the Main Woodland Survey (MWS) of woods ≥2 hectares, and the Survey of Small Woodland and Trees (<2 ha). The MWS is composed of a digital woodland map (derived from 1:25 000 aerial photographs) and a ground sample survey to evaluate woodland information, such as species, age and stocking (Forestry Commission 2003). Survey fieldwork was undertaken between 1994 and 2000. A second forest inventory (NIWT2) is being developed.

The Forestry Commission supplied a version of the NIWT database that had been analysed by 20km grid cell and split by ownership into Forestry Commission and non-Forestry Commission woodland. This dataset contained woodland over 2 hectares in extent and had been updated to 2001 (J. Gilbert, pers. comm.). (The area of 1990s planting will therefore be different from those published in the original NIWT reports, which did not include the full decade of planting). There is not complete coverage of the country because some cells (coastal and parts of the Northern and Western Isles) contain no woodland and therefore have no NIWT record. There is no equivalent woodland inventory for Northern Ireland.

A distinction must be made between the establishment date and the afforestation date when using the NIWT dataset (Thomson 2006). The establishment 'date' (within a decade) for a woodland stand is inferred from the average age of its trees recorded by the NIWT sample survey. For newly planted ('afforested') woodland the establishment dates and the planting dates should be equivalent. However, it should be noted that: (1) not all woodland established within a certain decade will appear in the equivalent age class in the NIWT, due to deforestation or disturbance, and (2) the NIWT does not distinguish between new planting and restocking of woodland.

7.2.4 Comparison of data sources

The reported areas of planting in the different datasets were compared with the national new planting statistics (Table 7-1 and Figure 7-1).

It can be seen that the area of 1990s-established woodland in the NIWT exceeds that reporting in the new planting statistics for the most part, because the NIWT figures include restocking. However, the new planting statistics exceed the NIWT estimates for all private woodland planting in Scotland and private broadleaf woodland planting in England and Wales. The explanation for these differences is unknown but may be related to the different sampling dates of the NIWT in the different countries.

The FC SCDB shows similarities to the annual patterns in the new planting statistics 1995-2006 but large discrepancies during certain periods (England 2002-03, conifer planting in Scotland and Wales). Forestry Commission planting in Wales is reported as zero in the new planting statistics for much of the period.

Table 7-1: Comparison of woodland established 1991-2000 recorded in the NIWT and new forest planting 1991-2000 recorded in the national statistics. Units in hectares.

		Forestry Commission (public)		**Non-Forestry Commission (private)**	
		Broadleaf	*Conifer*	*Broadleaf*	*Conifer*
England	*NIWT*	3 680	13 541	22 395	10 091
	NP statistics	165	290	41 165	6 403
Scotland	*NIWT*	1 709	24 071	7 754	18 533
	NP statistics	987	10 770	43 607	61 835
Wales	*NIWT*	1 282	15 082	1 877	2 675
	NP statistics	18	82	3 911	1 275

The WGS database matches well with the new planting statistics for England and Wales for 1996-2006. There are differences between the WGS and new planting statistics for Scotland during the earlier part of the period (although the pattern of planting is the same) but the areas agree from 2004 onwards.

7.3 Methods for spatial modelling work

The woodland planting datasets were harmonised so that they all had the same 20km cell reference system. The FC SCDB and NIWT data were already in this format, and the WGS data was converted into 20km grid cell data by proportional assignment and summation in ArcGIS. The Northern Ireland data will be re-analysed in the same way when the geographic data becomes available. A Matlab script was written to extract all records of planting between 1990 and 2000 from the NIWT dataset.

The proportion of new planting within the total NIWT planting area had to be estimated. The split between new planting and restocking in broadleaf woodland is similar for all woodland and for private woodland alone for England, Scotland and Wales. However, there is a difference in the split for conifer woodland between all woodland and private woodland alone. The proportional splits also vary over time. The estimated split by species type and ownership type for the NIWT 1990/91-1994/95 data was assumed to be the same as the average proportional split 1995/96-1999/2000 for the FC SCDB and WGS data (Table 7-2).

Table 7-2: Ratios between new planting and restocking 1995/96-1999/2000

	FC forest, New planting: Restocking		**Non-FC forest, New planting: Restocking**		**All forest New planting: Restocking**	
	Broadleaf	*Conifer*	*Broadleaf*	*Conifer*	*Broadleaf*	*Conifer*
England	16:84	2:98	77:23	45:55	75:25	18:82
Scotland	20:80	9:91	83:17	71:29	80:20	51:49
Wales	11:89	6:94	61:39	20:80	56:44	5:95
N.Ireland					76:24	47:53

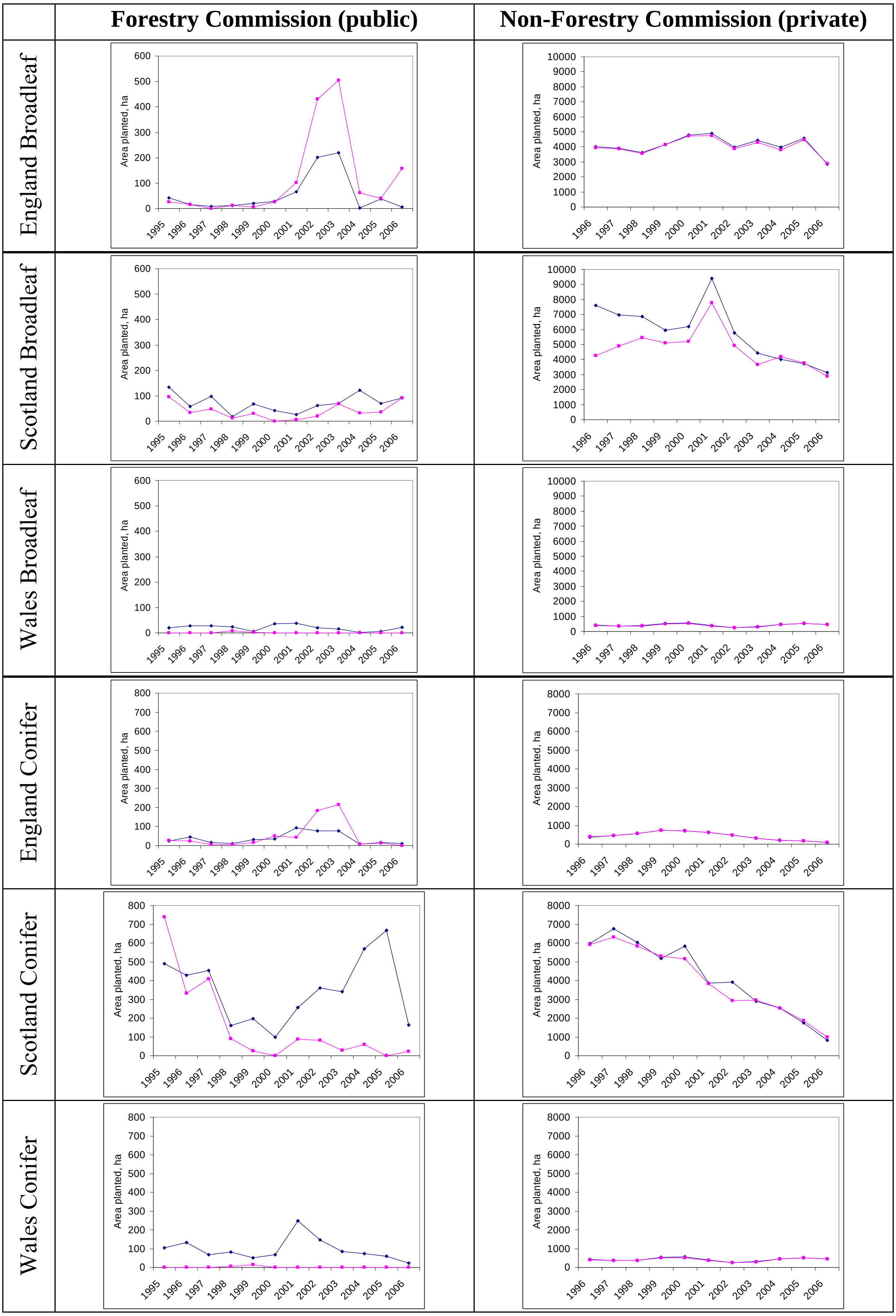


Figure 7-1: Area of new planting from FC SCDB and WGS databases (blue) vs. national afforestation statistics (pink).

There is insufficient confidence in the NIWT absolute values for planting at this time to justify their replacing of the national planting statistics for 1990-1995. However, the NIWT does give the distribution of forest planting and the relative proportions of broadleaf and coniferous planting, and of FC and non-FC planting in each square (but not the relative proportion of new planting and restocking). The FC SCDB and WGS give the species and ownership distribution of new planting and restocking from 1995 onwards. The reported numbers are in reasonable agreement with the national FC planting statistics but there are still some areas of concern. Until these data issues have been resolved the planting areas from each data set will be weighted by country so that they match the country reported total in the FC national statistics.

Separate tables of new planting were created for each year and species type (coniferous or broadleaf). Two sets of tables were produced: one for results by planting year (1st April-31st March), as used in the UNFCCC GHG inventory, and the other for results by calendar year (1st January -31st December).). This is to take account of the fact that the Kyoto Protocol strictly runs from 1st January 1990. The adjusted values for calendar year planting for 1990 for example are calculated by

*(Area in planting year 1990 * 0.25) + (Area in planting year 1991 * 0.75)*

There are minimal differences between the two datasets. The datasets were formatted so that they could be used in the ArcGIS geographic information system using the SQUID as the common attribute for joining datasets.

7.4 Results of spatial modelling work

Planting datasets for new planting in Great Britain split by ownership and broadleaf/conifer for 1990 to 2005 are now available. Example maps of planting in 1990 by ownership and cumulative planting 1990-2005 are shown in Figure 7-2 and Figure 7-3. These datasets can be used in the C-Flow model to produce estimates of carbon fluxes from afforestation at the 20km grid scale. This will help to achieve the UK's aim of reporting activities under Article 3.3 of the Kyoto Protocol at the 20km grid scale.

7.5 Future objectives of spatial modelling work

- Adaptation of the C-Flow model to use spatially disaggregated inputs
- Estimation of split in conifer planting between organic and mineral soils at the 20km grid cell scale
- Harmonisation of the Northern Ireland planting data with the other datasets
- Further analysis of the differences in planting patterns under public and private ownership and an investigation of the impact that this has on carbon fluxes
- Development of the methodology for pre-1990 planting (for estimation of carbon fluxes from Forest Management activities under Article 3.4 of the Kyoto Protocol).

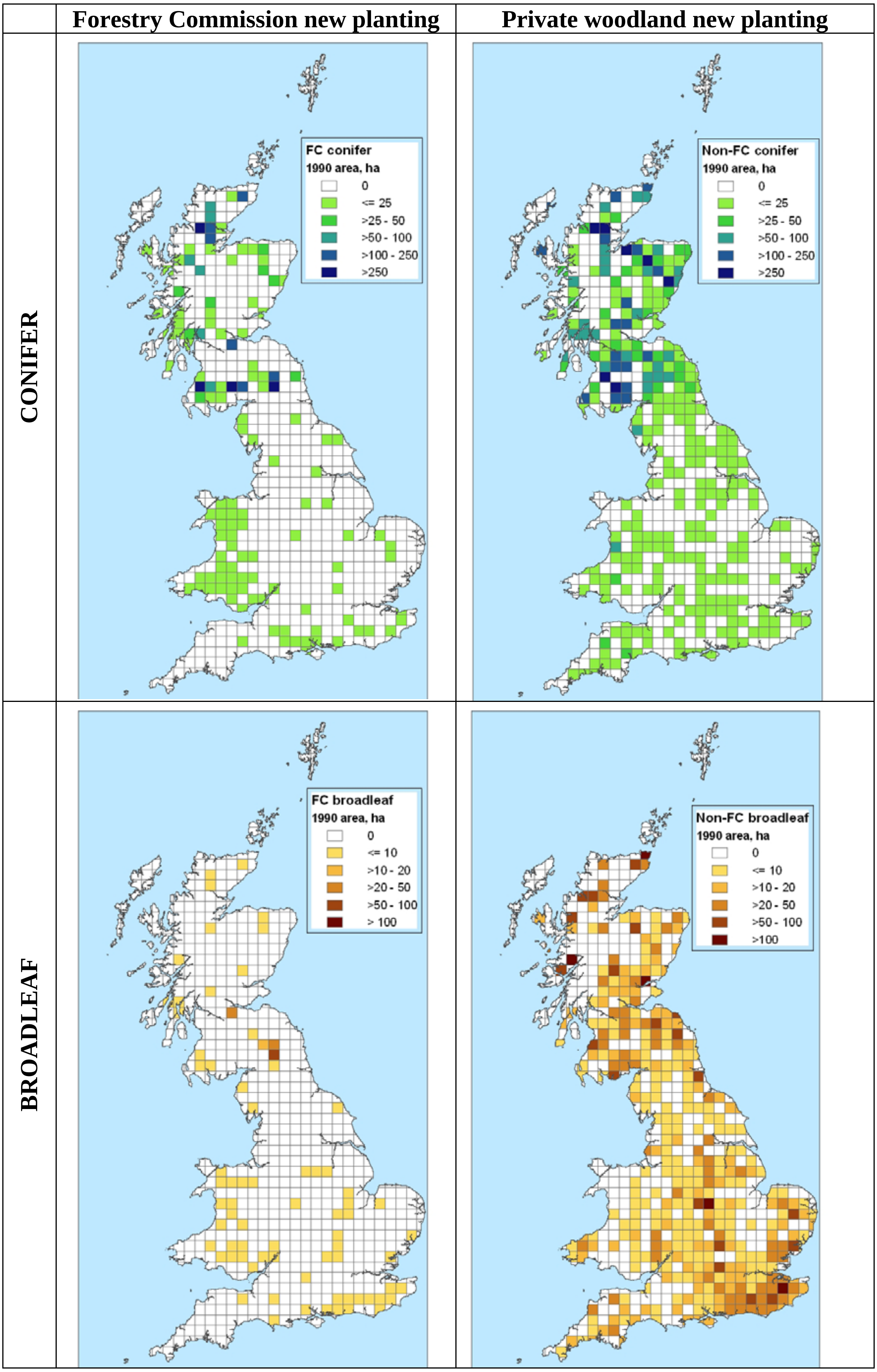
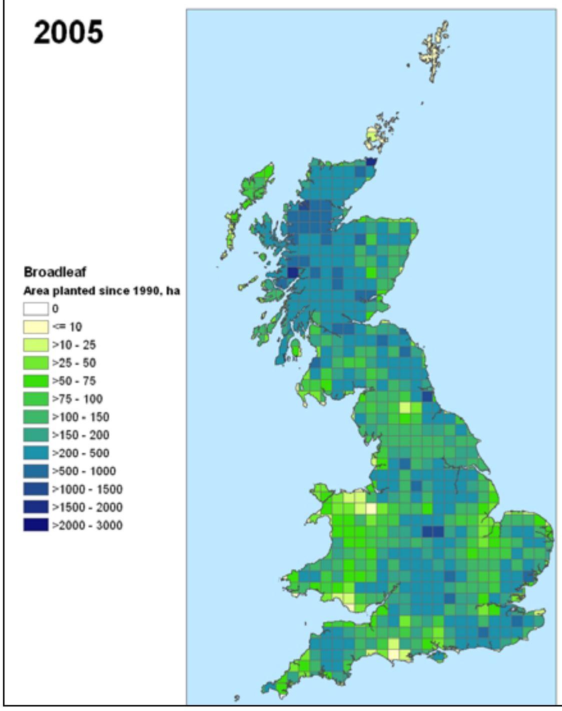


Figure 7-2: New planting in 1990 split by ownership and broadleaf/conifer

Broadleaf new planting



Conifer new planting

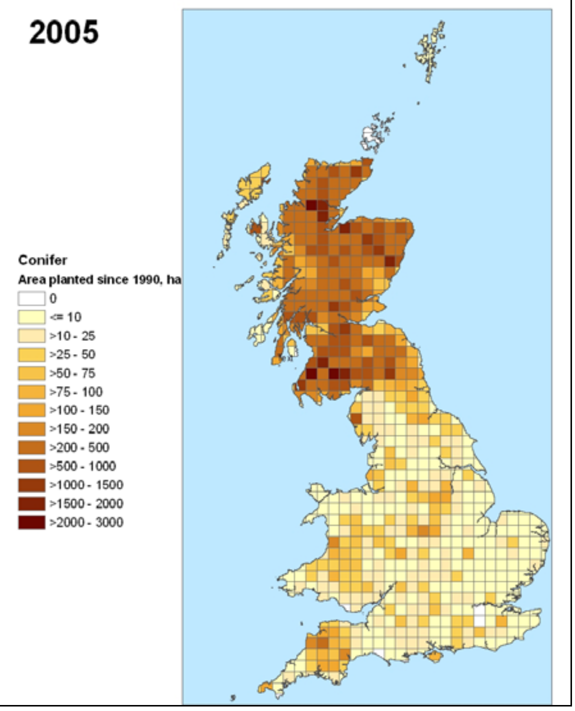


Figure 7-3: Cumulative new planting in Great Britain 1990-2005

7.6 The Production Forecasting Exercise in the Forestry Commission

Forests represent a significant carbon stock. If carbon sequestered within forests is to be estimated accurately (see chapter 8, WP2.4), then there is a fundamental requirement for a database of forest areas and stand composition, and a reliable approach to forecasting how forest species and composition may change over time.

The UK Forestry Commission (FC) uses a methodology for Production Forecasting (PF) (Forestry Commission, 2004), which is calculated every year, and formally published for softwoods every 5 years [PFs for private estates are calculated and published on a 5-yearly basis]. Currently about 57% of UK forest is softwood, accounting for 94% of production (Forestry Commission, 2006). The most recently published (2005) PF covers softwood availability from the Forestry Commission (Great Britain), the Forest Service (Northern Ireland) and potential softwood availability from the Private Sector (United Kingdom). The 2005 PF and a comparison with the 2000 PF forms the basis of milestone WP2.3:II and contributes to a better understanding of potential impacts of uncertainty in inventory data and management information on estimates of carbon stocks. Longer term scenarios may be used, incorporating changes in management, species and composition (WP2.3). PFs for hardwoods are also carried out, though these are not published so formally.

7.6.1 Developments in the 2005 PF

The PF in 2005 represented a major revision of 2000 improving representation of the forest estate and its management through:

- More complete and accurate stand data
- More comprehensive management plans
- Appropriate representation of intended management

More complete and accurate stand data.

An example from the Private Sector forecast for Scotland can be used to demonstrate how this has been achieved. The distribution of yield classes has changed substantially between the 2000 and 2005 exercise. The primary reason for this change is largely due improved assumptions about the yield class distribution in private woodlands (Figure 7-4), as discussed in Halsall *et al* (2006).

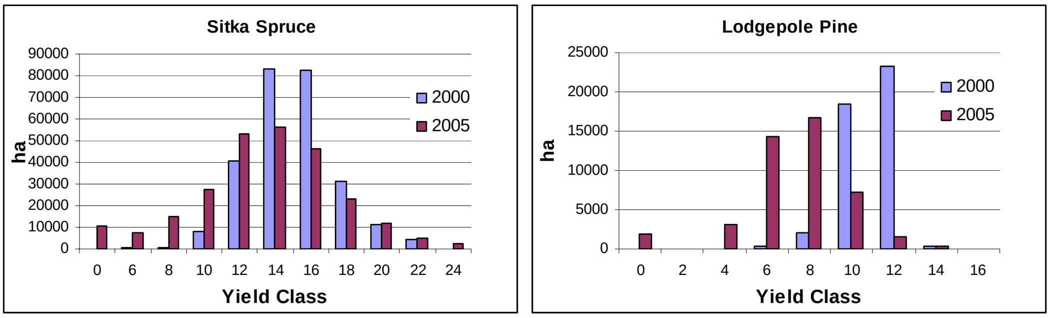


Figure 7-4: Comparison of yield class distribution in the Scottish Private Sector PFs in 2000 and 2005. The two example species (Sitka spruce Lodgepole pine) represent about 58% and 10% respectively of the Private Sector PF woodland in Scotland.

More comprehensive management plans - Restocking species changes

Tree species being selected for restocking felled areas are undergoing major changes. Much of the coniferous forest is being diversified. In the case of England, the diversification involves significant emphasis on broadleaf species. Table 7-3 shows the indicative re-stocking prescription in North England. In the Private Sector these prescriptions are encouraged by the use of planting grants. PFs can be run to account for replacing the current coniferous forest with the broadleaf trees, and also to account for management involving greater areas of open ground.

Evolving forest management

Increasingly, the management of forests is changing to address new policy-driven, commercial and environmental objectives. In practice many areas of forest are now being managed according to “Low Impact Silvicultural Systems” (LISS). These low impact systems include shelterwood and selection silviculture, minimum intervention and ‘biological retentions’.

For example, The Welsh Assembly has directed the Forestry Commission to change its restocking policy and to accelerate the delivery of LISS in FC woodlands throughout Wales (FC Wales National Committee, 2003). Table 7-4 summarises the position in the Assembly Woodlands in 2005. In future years, the amount of woodland managed under LISS will increase. Note that the PF area is not the same as the land area; it includes High forest, understorey and windblow areas where production is deemed practical and economic, but does not include felled, coppice or intruded broadleaves.

Table 7-3: Indicative re-stocking prescription for coniferous forests in North England (as assumed in the 2005 PF)

Species felled	YC felled	Restock prescription
SP	<= 8	10% to open ground, 45% to broadleaves, remainder as SP
SP	>= 10	10% to open ground, 27% to broadleaves, 18% to JL/HL, 18% to CP, remainder stays as SP
CP		10% to open ground, 27% to broadleaves, remainder as CP
LP		50% to not restocked/broadleaves, remainder convert to SS
SS	<= 8	10% to open ground, 90% BI
SS	>= 10	10% to open ground, 18% broadleaves, remainder as SS
NS		10% to open ground, 25% broadleaves, 27% to SS, 9% to DF, remainder stays as NS
EL		10% to open ground, 45% broadleaves, 23% to SP, 22% to JL/HL
JL/HL	4, 6, 8	10% to open ground, 50% broadleaves, 18% to SS
JL/HL	>= 10	10% to open ground, 36% broadleaves, 18% to DF, 18% to SS, remainder stays as JL/HL
DF	<= 10	10% to open ground, 60%broadleaves, 15% to SS, remainder stays as DF
DF	>= 12	10% to open ground, 18% broadleaves, remainder stays as DF
XC		10% to open ground, 54% broadleaves, 18% to SP, 18% to SS
MC		10% to open ground, 45% broadleaves, 9% to SS, 18% to SP, 18% to JL/HL

SP: Scots pine; JL/HL: Japanese larch/Hybrid larch; CP: Corsican pine; LP: Lodgepole pine; SS: Sitka spruce; BI: Birch; NS: Norway spruce; DF: Douglas fir; EL: European larch; XC: other conifers; MC: mixed conifers.

Table 7-4: Summary of areas in Welsh Assembly Woodlands managed according to traditional and LISS regimes

	District Area (ha)	PF area (ha)	LISS area (ha)	LISS of PF (ha)
Coed y Cymoedd	30430.9	18930.5	7645.8	5471.4 (28.9%)
Coed y Mynydd	38862.8	22984.6	8518.6	5512.9 (24.0%)
Coed y Gororau	22730.9	16398.2	6427.0	5289.4 (32.1%)
Llanymddfri	35987.8	25359.7	9581.6	6422.5 (25.3%)
Total	128012.4	83673.0 (65.4%)	32173.0	22676.2 (27.1%)

Note that the PF area is not the same as the land area; it includes High forest, understorey and windblow areas where production is deemed practical and economic, but does not include felled, coppice or intruded broadleaves.

The Forestry Commission PF system permits Forest Districts to make detailed descriptions of the composition of woodlands and intended management. The 2005 PF system recognises all the major types of LISS regime and makes appropriate adjustments to forecasts.

Appropriate representation of intended management

Changing management away from the traditional to LISS regimes may have a large effect on the volumes (and carbon) produced by a forest (Figure 7-5). Managing woodland under a LISS regime may reduce or increase the carbon-stock, particularly as woodland develops over time.

For example in the 2005 PF fore the Private Sector woodlands in Wales, special yield models were developed to reflect the changes in stand management occurring as a result of the introduction of LISS. Although the primary objective was to understand potential impacts on timber production, the models also describe potential impacts on the growing stock. In Figure 7-5, the changes in carbon in merchantable stem wood is illustrated for two yield models; one based on a traditional management regime and the other on LISS. In this example, the long term average carbon stock in standing stem wood in the stand managed under LISS is more than twice the stock in the stand under traditional management.

It must be emphasised that this is just one scenario. Better understanding is needed of the potential impacts of evolving management on forest carbon stocks.

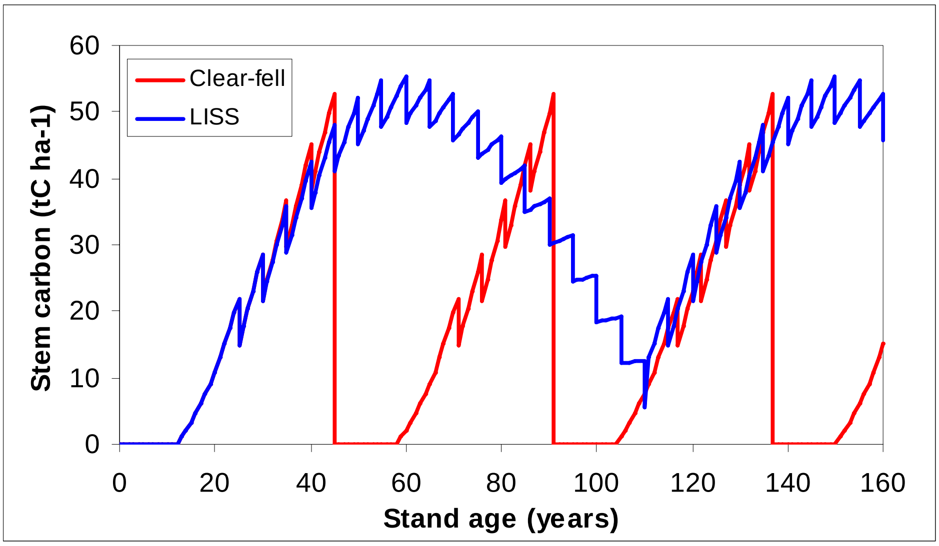


Figure 7-5: Differences in standing stem carbon in a Sitka spruce stand, Yield class 12, 2.0m spacing, managed according to a traditional thin and clearfell regime.

7.6.2 Effects of improved management and data.

The many improvements and changed assumptions in the 2005 PF have resulted in some notable changes in forecasts of timber volume availability compared to the 2000 PF, as illustrated in the results for the Private Sector in Figure 7-6.

Impacts on estimates of the growing (carbon) stock in the GB forests are likely to mirror these changes in estimates of production. The potential sensitivity of the forecast results to uncertainties in these data and assumptions about future management emphasises the requirement for a robust, verifiable forecast methodology.

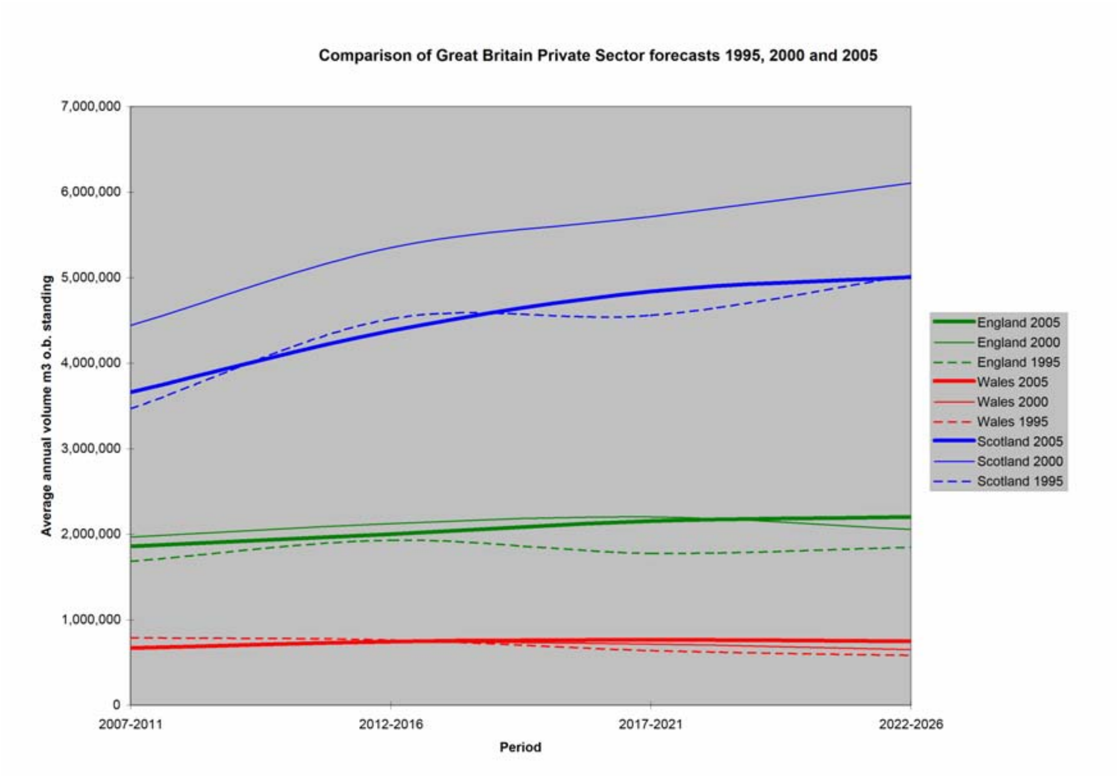


Figure 7-6: Availability of softwood timber volume in the Private Sector as forecast in 1995, 2000 and 2005 for the GB mainland.

7.6.3 Future developments

Forecasts are likely to undergo further changes as new research findings are accounted for. For example, Forest Research has recently completed the development of a new dynamic growth and yield model for Sitka spruce stands, know as M3. This model is capable of representing a much wider range of stand management regimes than was previously possible. The M3 model also suggests that estimates of stand yield class based on top height may need to be revised, although the adjustments required depends on the age of the stand when the height assessment is made. Table 7-5 give the suggested adjustments to yield classes based on the existing published yield models for Sitka spruce (Edwards and Christie, 1981) when top height is assessed at age 50.

Table 7-5: Percentage allocations of Booklet 48 ('old') General Yield Classes for Sitka spruce to M3 yield classes at a reference age of 50 years. Mean equivalent ('new') .yield classes are also shown.

Old	Allocation to M3 yield classes (per cent)													Mean new
	4	6	8	10	12	14	16	18	20	22	24	26	28	
6	8	92												5.8
8		7	93											7.9
10			25	75										9.5
12				41	59									11.2
14					41	59								13.2
16						36	64							15.3
18							24	76						17.5
20								29	54	17				19.8
22										55	45			22.9
24											34	66		25.3

The Forestry Commission has recognised a requirement to develop a more comprehensive, robust, transparent and verifiable methodology for forecasting and scenario analysis in British woodlands. Work has begun on specifying this system, beginning at a high level in terms of inputs and associated outputs. Hierarchical levels of input can be defined, in terms of the level of detail provided, with more information permitting a wider range of forecast outputs, greater detail and estimates in confidence. Four major levels, 'minimal', 'basic', 'partial' and 'complete' have been specified. The specification for 'basic' level information is summarised in Table 7-6.

There is an opportunity to achieve convergence of the FC forecast system development work with the methodology for estimating and reporting LULUCF carbon.

Table 7-6: High level specification of the forecast system for the 2010 PF exercise in terms of inputs and associated outputs (Basic level). Matthews (2006)

Inputs				**Outputs**
Basic inventory	**Prescription**	**Area change**	**Forecast variables**	
Total forest area for region of interest (conifer, broadleaf, mixed) in combination with: (%) Species distribution (%) Age class distribution [by species] (%) Yield class distribution [by species and age class].	Basic management prescription (initial spacing + non-thin, standard thin, [line thin, LISS, etc.]) in combination with fell age distribution (where appropriate) [by species, age class and yield class].	[Rules for: Restocking forest area (ha or %) in terms of species, yield class, basic management prescription and fell age (where appropriate) as areas are felled or regenerated under LISS. Loss of forest area (i.e. conversion to other land cover/uses, ha or %) [in terms of species, yield class, basic management prescription and fell age] as areas are felled or regenerated under LISS. Additions to forest area (i.e. conversion from other land cover/uses, ha or % per period) in terms of species, yield class, basic management prescription and fell age (where appropriate).]	Forecast period and intervals for reporting Availability of: [Numbers of trees Stem volume Volume of specified products Total biomass Woodfuel (to specification)]. Growing stock: [Numbers of trees Basal area (Mean) dbh Stem volume Total biomass Total carbon 'Increment' 'stand Structure'].	Totals/means of specified forecast variables for complete area and by species (groups). Forecasts based on tabular calculations. Values reported over forecast period at specified intervals. No confidence intervals.

7.7 References

Edwards, P.N. and Christie, J.M. (1981) *Yield Models for Forest Management*. Forestry Commission Booklet 48, Forestry Commission, Edinburgh.

FC Wales National Committee, (2003). *Delivering the changing the restocking and Liss policies*. Wales National Committee Meeting, NC 04/03 (30th May 2003). http://www.forestry.gov.uk/forestry/INFD-5VGDUK. Accessed 06/06/07

Forestry Commission, (2003). *National Inventory of Woodland and Trees. Great Britain*. Forestry Commission, Edinburgh.

Forestry Commission (2004). *Production Forecasting. OGB 32*. Forestry Commission, Edinburgh, UK.

Forestry Commission (2006). *Forestry Facts and Figures 2006*. ISBN: 0 85538 706 8, Forestry Commission, Edinburgh, UK.

Halsall, L., Gilbert, J., Matthews, R. and Fairgrieve, M. (2006) United Kingdom: New Forecast of Softwood Availability. *Forestry and British Timber*. **35(11),** pp14-23.

Matthews R W (2006). FC forecast 2010 system. *FR internal report V1.2*. February 2006.

Thomson, A.M. (2006). Variations in forest management in Great Britain. In: Milne, R. and Mobbs,D. (eds.). *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry*. Annual report, 2006, for Defra contract EPG 1/1/160.

7.8 Acknowledgements

We gratefully acknowledge the assistance of Alan Tregoning and Lesley Halsall of the Forestry Commission, Justin Gilbert of Forest Research and Jim McEwan of the Northern Ireland Forest Service in supplying the datasets used for the spatial modelling. We thank Deena Mobbs for writing the Matlab script for the NIWT dataset.

8. Verification of carbon stocks in forest biomass using forest inventory data (WP 2.4)

Randle, T., Matthews, R., Brewer, A., Baldwin, M., Mackie, E
Forest Research, Alice Holt

8.1 Introduction

The monitoring methodology of forest carbon stock and stock changes (milestone WP2.4: II) is intended to integrate with the second FC National Inventory of Woodland Trees (NIWT2). Its purpose is to evaluate the extent and the properties of woodland over large areas. This will be achieved through a comprehensive mapping exercise coupled with systematic sample of inventory plots across the GB forest estate.

The main focus will be to determine properties of woodlands over a large geographic area by aggregating the results of observations made on the individual plots – thus, there is less intrinsic interest in the properties of any individual plot forming the sample.

Brewer *et al.* (2006) have described the main inventory plot assessment protocol, which permits estimating of a range of tree and stand variables including carbon stocks. A degree of flexibility is needed in the method of observation and assessment in order to deal with plots falling in woodlands that will vary considerably in composition and structure. Accordingly, the protocol provides alternative assessment methods. Despite this, the information gathered using the different methods can be summarised in a common format for both aggregation and comparative purposes.

8.2 Summary of protocol

Location 1 ha sample-squares

The location and orientation of the 1 ha sample-squares are predetermined as part of the NIWT2 survey design.

Overview of the procedure for assessment of each sampled 1 ha square

Prior to the assessment visit an aerial photograph is taken of the square and its surrounds. Boundaries of the square are superimposed on the photograph and an initial assessment is made of separate identifiable sections of woodland within the square according to the conventions. The boundaries of these sections are also superimposed upon the photograph, both within and outwith the sample-square. Each section falling inside the square is measured and recorded. Provisional sampling points for the mensuration assessment will be assigned to each section within the square as below.

The assessor will be provided with this information in advance, and upon reaching the site, the sectioning of the square (on the basis of the aerial photograph) will be verified by ground survey of the site. If inaccuracies are detected, or if features are observed during the ground level inspection which affect the optimum partitioning of the square into sections, adjustments to the section plan will to be made on site.

A survey is made of the square in which an inventory of the tree species present in the square is made, and each identified section is assessed for the presence of separate strata.

The main assessment protocol is undertaken for each stratum within each section of the square.

At the end of the survey of each stratum, a list is made of the species captured in the survey. The list is annotated with an assessment of the type of spatial distribution of the species within the section and its representation in the stratum. A code will be assigned according to whether the species is pure, intimate, patchy or linear.

8.3 Detailed specification of protocol

The full protocol of Brewer *et al.* (2006) cannot be repeated here. To illustrate the level of detail in the protocol, the description of how to make assessments of tree vertical structure used in stratification of tree forming sections is repeated below.

Before attempting to group trees into separate storeys according to their general vertical stature, it is necessary to identify a definitive concept of the height of any 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 - since tree canopies can vary considerably in shape and form, the overall tree height 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 (the 'mid-crown' height).

Precise definition of the top and bottom of the crown of any tree can be made with reference to the crown measurements described fully in the protocol. The top of the crown is the apex of the tree, while the bottom of the crown is identical to the lower crown height. The mid-crown height is therefore the midway point between the lower crown height and the total height of the tree. Figure 8-1 illustrates examples of the positioning of the lower, total and mid-crown heights for both conifer and broadleaf species.

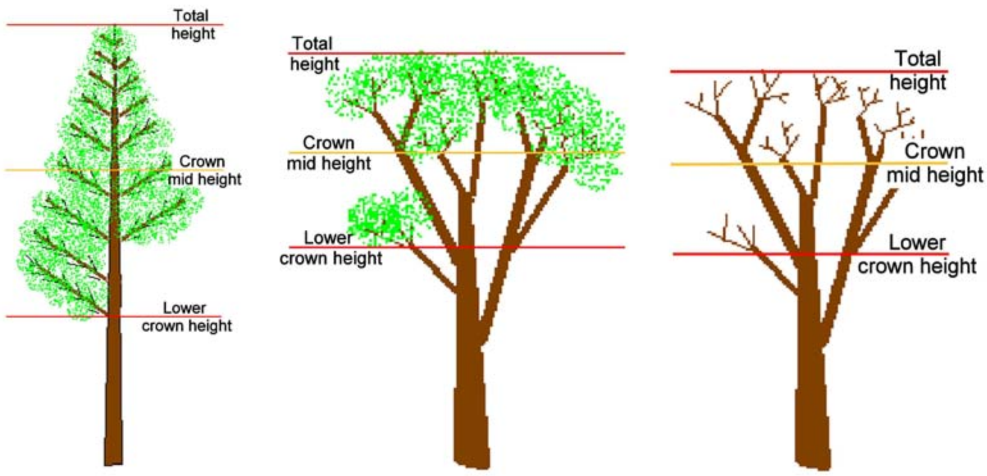


Figure 8-1: Assessment of total height, lower crown height and hid height in conifer and broadleaf trees.

Using mid crown height to determine storeys

It is likely that woodlands may contain a range of canopy profiles, particularly if a mixed woodland. Figure 8-2 shows two bands of projected crown mid-heights; in this instance the members of the upper storey are widely spaced and therefore sparse. This storey is still treated as a separate stratum but its properties may dictate a different method of assessment than is used for the lower storey:

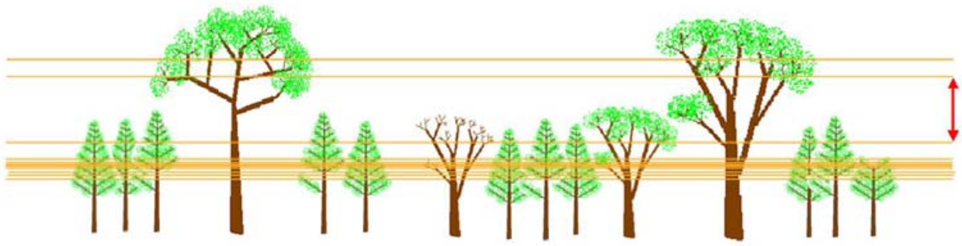


Figure 8-2: Identification of two storeys in a stand of trees.

8.4 References

Brewer A., Matthews R., Mackie E. and Baldwin M. (2006) *NIWT 2: Protocol for assessment of woodland composition, structure and growing stock*. FR internal report for the NIWT management board.

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

P.E. Levy
Centre for Ecology & Hydrology, Bush Estate, Penicuik

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. The Scottish Forestry Alliance manage nine sites in Scotland where recent planting has taken place, and baseline surveys of soil carbon have been carried out at the time of planting (Meir *et al*, 2003). At a sub-set of these sites, we propose to measure soil carbon in stands of varying age, and compare this with the baseline data quantifying the soil carbon prior to planting. The priority sites to be re-sampled will be Abernethy Forest Reserve, Glen Finglas, Glen Sherup and Geordie's Wood, and an experimental plan has been produced, based on the baseline survey. The field work is planned for summer 2008.

Meir P, Conen, F and Nagy, L (2003) Baseline survey of carbon stocks at selected SFA sites in Scotland. Interim report for 2003, covering measurements made at three sites: Abernethy Forest Reserve, Glen Sherup and Darrochwids. Unpublished report to SFA/BP/ECCM, Edinburgh.

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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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 is 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. Recent work (Smith *et al*. 2004) suggests that the increase in N_2O emissions in "no-till" agriculture outweighs the effect of carbon sequestration, in terms of Global Warming Potential (GWP). As a secondary aim, 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

10.2.1 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 relatively shallow (10-20 cm), but relatively high in organic matter (10 % carbon content).

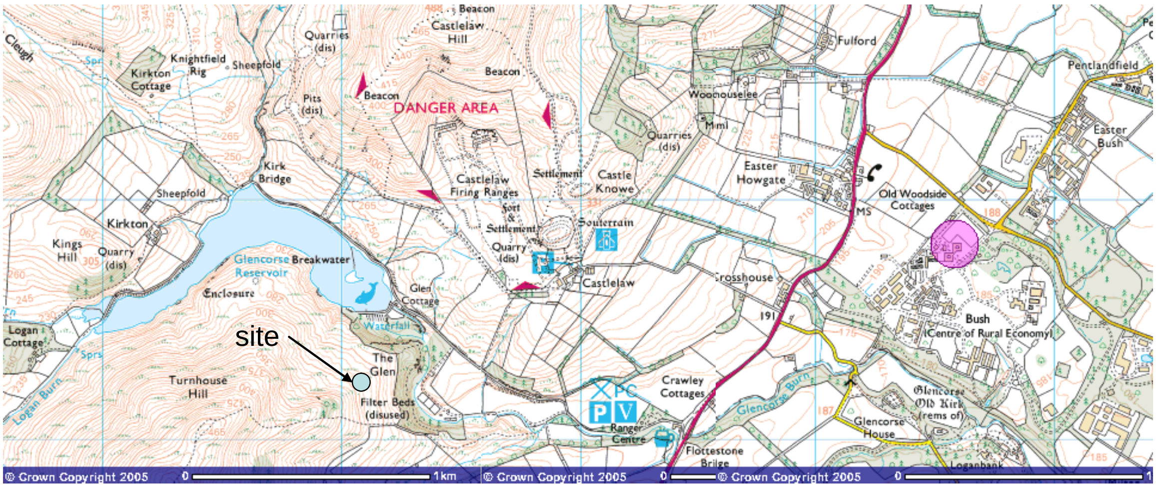

Figure 10-1: Location map of experimental site at House O' Muir Farm.

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 bi-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 turfs. For treatment 2, this cultivation was repeated annually, in May 2006 and May 2007.

10.2.2 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. Taking deeper cores proved impractical because of the limited soil depth. Samples were analysed at CEH Lancaster for total carbon by loss on ignition (LOI) and bulk density. A sub-sample of 18 cores were analysed using an Elemental Analyser for carbon and nitrogen content. These data were used to establish the following relationship between LOI and carbon content (C):

$$C\,(\%) = 3.1959 + 0.332 \cdot LOI\,(\%)$$

which was applied to the other samples to calculate carbon content.

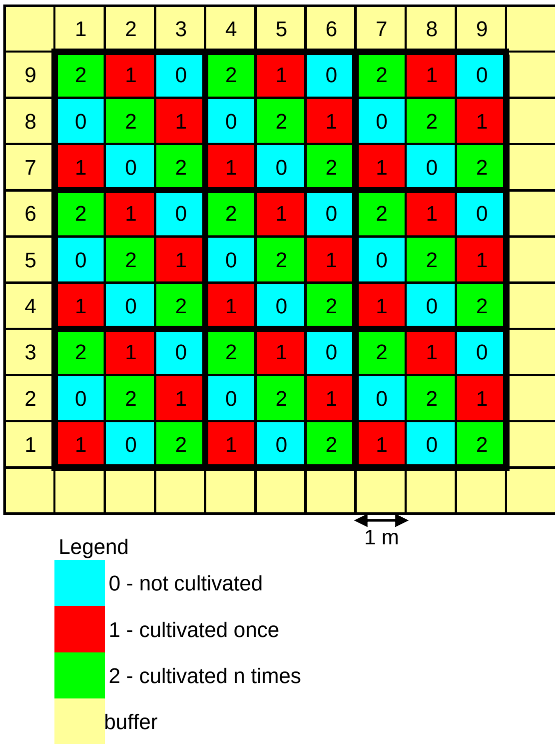

Figure 10-2: Replicated Latin Square experimental design, showing 11 x 11 m area with three treatments applied to 1 x 1 m plots in a 3 x 3 Latin Square, repeated 3 x 3 times.

10.2.3 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 and 18 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

$$R = dCO_2 /dt \cdot w$$

where dCO_2 /dt is the rate of increase in CO_2 with time (μmol mol^{-1} 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.

10.2.4 N_2O and CH_4 flux measurements

N_2O and CH_4 fluxes were measured in May 2006 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 and gas samples were collected in portable evacuated aluminium vials (Scott *et al*., 1999). Samples were analyzed for N_2O by electron capture and for CH_4 by flame injection gas chromatography.

10.3 Results and Discussion

The previous report (Levy *et al*. 2006) showed that there were no significant differences in soil carbon or respiration rates between the plots allocated to the different treatments, prior to cultivation. 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. The results here suggest that CO_2 emissions were higher in the uncultivated treatment (Figure 10-3), and this is close to significant levels ($p = 0.07$, Table 10-1a). The most likely explanation is that the effect on decomposition was very rapid immediately following cultivation, with the labile pools of carbon being respired within six months, such that substrate levels and thus respiration rates were lower than in the control by May 2006. Without the measurements of soil carbon loss originally planned for year 3, we cannot draw definite conclusions about this.

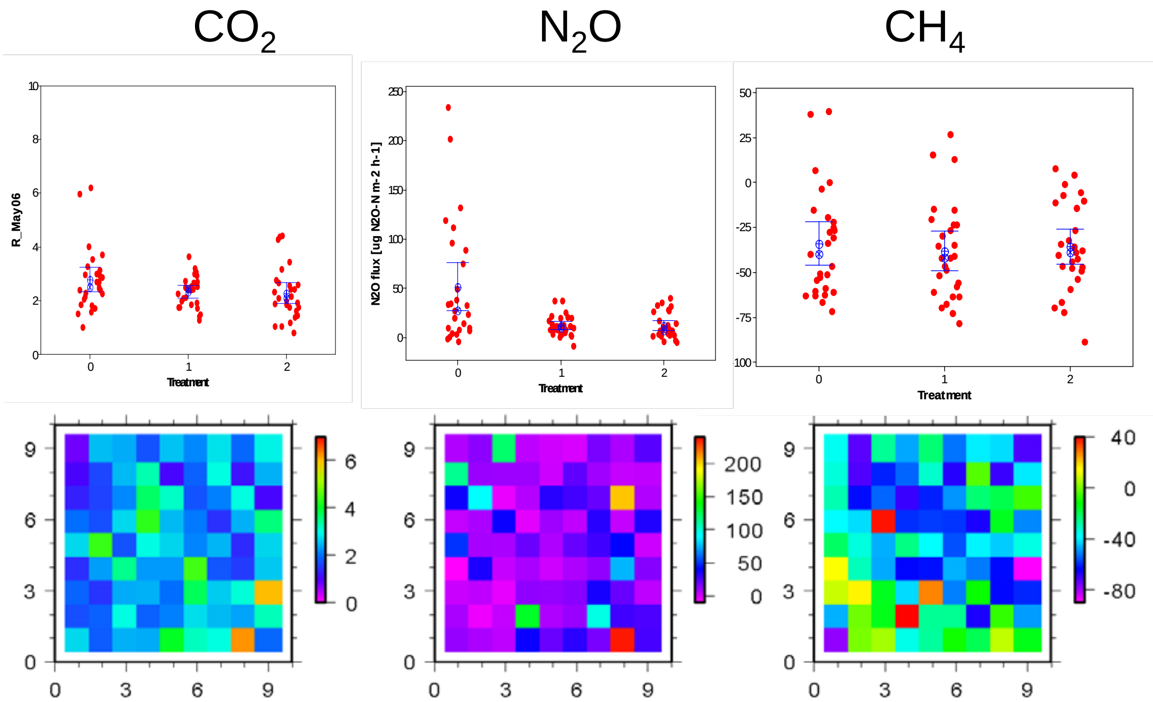

Figure 10-3: Upper row: interval plots showing the fluxes of CO_2, N_2O, and CH_4 by treatment, measured in May 2006, six months after the first cultivation. Treatments are: 0 – uncultivated control; 1 – cultivated once; 2- cultivated annually. Error bars show 95 % confidence intervals. Only N_2O fluxes show differences significant at the 95 % level. Lower row: Spatial distribution of the above data. X- and y- axes are the spatial position within the experimental area, in metres. The origin is the NE corner of the area.

Figure 10-3 and Table 10-1b show that N_2O emissions were significantly lower in the cultivated treatments ($p<0.001$). 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 Bøckmann, 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 10-3 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 Table 10-1c shows no significant differences in CH_4 fluxes.

Table 10-1: Analysis of Variance tables for differences between treatments in the fluxes of CO_2, N_2O, and CH_4, accounting for the spatial variation by blocking according to the 3x3 m Latin square in which the plot occurs (thick black lines in Figure 10-2).

(a) Analysis of Variance for CO_2 flux

Source	DF	SS	MS	F	P
Treatment	2	4.1968	2.0984	2.73	0.072
Block	8	16.6198	2.0775	2.70	0.012
Error	70	53.8974	0.7700		
Total	80	74.7140			

(b) Analysis of Variance for N_2O flux

Source	DF	SS	MS	F	P
Treatment	2	28320	14160	11.26	0.000
Block	8	21005	2626	2.09	0.048
Error	70	88009	1257		
Total	80	137334			

(c) Analysis of Variance for CH_4 flux

Source	DF	SS	MS	F	P
Treatment	2	220.0	110.0	0.18	0.834
Block	8	16989.8	2123.7	3.51	0.002
Error	70	42372.6	605.3		
Total	80	59582.4			

As a preliminary attempt to estimate the impact of cultivation on the overall greenhouse gas balance, we calculate the total greenhouse warming potential (GWP). GWP is calculated by adding changes to the N_2O and CH_4 fluxes to the change in soil carbon stock, weighted by their relative effects on radiative forcing (297 and 23, respectively). Here we calculate the change in GWP relative to the control. Because it has not yet been measured, we estimate the change in soil carbon assuming it is proportional to the change in soil respiration. This is likely to overestimate the change, as respiration will be more sensitive to the change in the labile pool, but serves to illustrate the method. Using this assumption, the cultivated treatments lost 214 g CO_2 m^{-2} more than the control over the first six months of the experiement. Assuming the N_2O fluxes can be applied over the whole six month period, the cultivated treatments emitted 0.54 g N_2O m^{-2} less than the control. Differences in CH_4 emissions can be ignored as there were no significant differences. Using a global warming potential for N_2O of 297 relative to CO_2 gives

$$GWP = 214 - (0.54 \times 297) = +54 \text{ g } CO_2 \text{ m}^{-2}.$$

Thus, the loss of soil carbon outweighs the reduction in N_2O emission at this point. We note that the two effects are of similar magnitude and the sign of the balance could be changed when this is calculated over a longer period, and when the measured change in soil carbon is used, rather than estimates. We note also that the spatial blocking term is highly significant in Table 10-1a-c, indicating that spatial variation is important and needs to be accounted for in the analysis. Our experimental design lends itself to more complex spatial analysis, e.g. spatial REML, and this will be pursued if necessary. An attempt to measure the ^{14}C component in respired CO_2 was made in November 2006 but failed to capture enough CO_2 for ^{14}C analysis. A modification to the method to increase the capture of CO_2 is currently being tested (May 2007) and will be reported on in the next report.

10.4 References

Davidson, E.A., 1991. Fluxes of nitrous oxide and nitric oxide from terrestrial ecosystems. In: Rogers, J. E., Whitman, W. B. (Eds.). Microbial Production and Consumption of Greenhouse Gases: Methane, Nitrogen Oxides and Halomethanes. Am. Soc. Microbiol., Washington, DC, 219-235.

Granli, T. and Bøckman, O.C., 1994. Nitrous oxide from agriculture. Norwegian Jounal of Agricultural. Science. Supplement 12, pp 128.

Milne, R., (2003). UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities. Annual report for Defra Contract EPG1/1/160. CEH, Edinburgh.

Paustian, K., Six, J., Elliott, E. T., Hunt, H. W. (2000). Management options for reducing CO_2 emissions from agricultural soils. Biogeochemistry, 48, 147-163.

Smith, K. A., Conen, F. (2004). Impacts of land management on fluxes of trace greenhouse gases. Soil Use and Management, 20, 255-263.

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 2.7)

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11.1 Introduction

Peatlands represent the largest store of carbon in UK ecosystems. 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 150 000 ha are “severely affected” by drainage, and major initiatives are in place to reverse this (LIFE Peatlands Project 2005). 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.

The original experimental plan was to measure the carbon balance on a drained site, before and after drain blocking. However, after extensive searching and consultation with land owners, no suitable sites could be found where drain blocking is planned in the next few years. Instead, we plan, and are in the process of setting up, a three-way comparative experiment with sites that are pristine, drained, and drain-blocked, at the RSPB reserve at Forsinard, Sutherland. The original 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 comparison 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 aspects. The sites chosen at Forsinard are very well-suited in this respect, all being within a few kilometres and otherwise similar.

11.2 Site and Methods

The research is focussed on 3 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:

1. Cross Lochs South – a 2 km^2 **pristine** peatland catchment which drains west from a bog-pool system to the River Dyke.
2. 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.
3. 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 constructed at a spacing of 50 m.

The use of three sites necessitates a change in methodology, as there is only one eddy covariance system for measuring landscape-scale CO_2 fluxes. The eddy covariance system will be located at the pristine site, to give the background atmospheric flux for the undisturbed state. 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. Changes in water table depth will be measured continuously at the pristine site and monthly at the other 2 sites. The fluvial fluxes will be measured at all three sites by monitoring discharge (continuously) and total carbon content (fortnightly water samples). Sites were selected in May 2007 and will be instrumented from June 2007. A post-doctoral researcher (Sarah Crowe) at the Environmental Research Institute (ERI) in Thurso, will carry out the bulk of water sampling and chamber flux work.

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

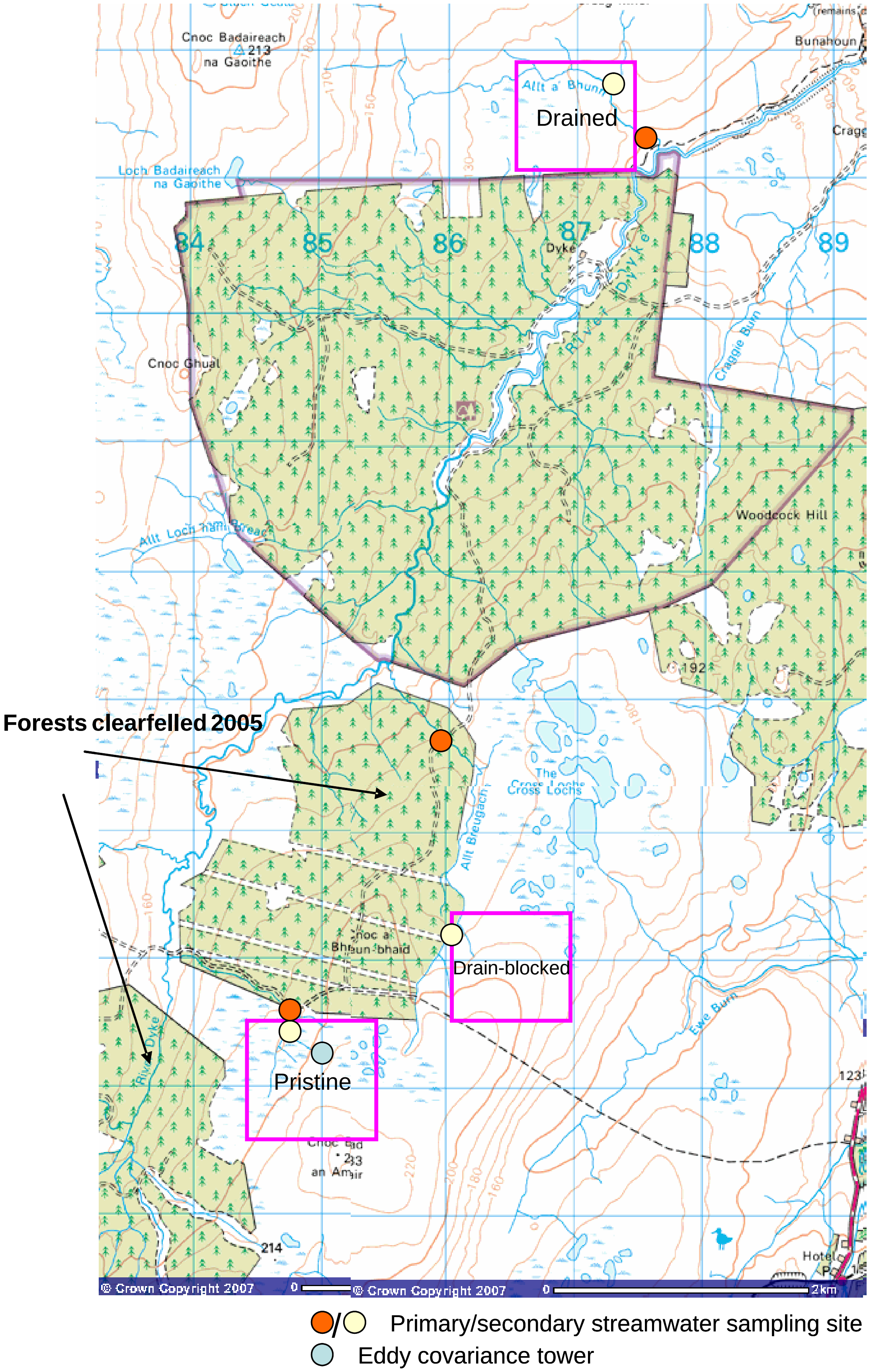

Figure 11-1: Location of the field sites and eddy covariance measurement tower within the RSPB Forsinard reserve, Sutherland.

11.3 Collaboration with partner institutes

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

- ERI (Sarah Crowe) – 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.

11.4 References

LIFE Peatlands Project (2005) The Peatlands of Caithness & Sutherland - Management strategy 2005 - 2015, pp 52.

11.5 Acknowledgements

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

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

Large losses of carbon from soils across England and Wales have been found in the samplings of the National Soil Inventory (NSI) between 1978 and 2003 (Bellamy *et al.* 2005). Changes in detailed land management within the broad land use categories recorded at the time of the sampling will undoubtedly have contributed to the carbon changes and there are likely to be complicated interactions between land use/management and climate change. The main objective of the first year of this study was to identify NSI sites where either detailed information on land management was available or the land management could be assumed.

12.2 Identification of study sites

A wide range of sources of information were examined:

Aerial photographs were available for an area of the Yorkshire Moors for a number of years from 1960 to 2000. Three NSI sites that had been resampled were within the area of the photographs for the years 1989 and 1995 (see Appendix 5).For the two upland heath sites it was possible to identify the sites on photos for 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 samples being taken. The techniques of Yallop *et al.* (2006) were used to determine the age of the burnt areas shown in Table 12-1. This burning management could have contributed to the loss in soil carbon shown at both sites which were sampled 20 and 22 years apart. However, with only two sites it will be 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 should be obtained within the next week or two and will be examined for similar trends.

The Countryside Survey (data from CS provided by the Centre for Ecology and Hydrology under license (www.CS2000.org)) had 1314 sites where measurements were taken in 1990 and 1999 in England and Wales and for which some management data was available. The positions of these sites were compared to the NSI sites and no CS site was closer than 1.9km to a resampled NSI site so will not provide any relevant information.

Table 12-1: NSI resampled sites

NSI_Site ID	Date of original sampling	Date of resampling	Original Organic Carbon (%)	Resampled organic carbon (%)	Land use	Management identified from aerial photos
11283	08/03/1983	31/03/2003	50.3	47.1	Upland Heath	Burnt 1-3yrs prior to 1989, recovering 1995, not burnt up to 2000
11284	27/01/1983	10/03/1997	5.8	5.44	Permanent Grassland	Permanent grass 1989/ hay cut 1995
11143	08/07/1981	11/04/2003	54.8	47.0	Upland Heath	Not burnt by 1989, still not burnt by 1995, but very close to burnt areas in both years

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.

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 burning of straw was stopped, whether straw was incorporated or removed from the field, tillage techniques, manure applications and some information on cropping cycles.

As part of a Defra project (SP0546) 28 soil sample sites which had already been visited on two previous occasions as part of the national map program were again revisited and soil samples taken. Although these were not part of the NSI dataset there is land management information available and the soil samples taken were analysed for organic carbon content.

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.

Data and site information from the ECN and from the Forest Inventory should be made available to us within the next few weeks. We hope that the forest inventory sites will give information on forest and woodland management over the period between the samplings so that even if the sites are not close to the woodland NSI sites it will allow some management methods to be assumed for these sites. There are 123 NSI sites with land use deciduous/mixed woodland and 111 sites under coniferous woodland.

12.3 Reconstruction of daily climate and soil moisture datasets for each site

Monthly records of climate including temperature, rainfall and solar radiation have been obtained for every NSI point from 1960 to 2005 and work is progressing on investigating the building of soil moisture records in collaboration with the NERC funded project 'An improved empirical model of soil carbon dynamics in temperate ecosystems'.

12.4 Initial statistical modelling

Investigation into possible statistical techniques has been made and the techniques to be applied will include hierarchical models to investigate the relationships between the change in organic carbon and other soil and climate properties. These models will allow the change at a site to be related to the other properties of that site including land management. The use of various software tools has been investigated – we shall use WinBugs (2004) to apply hierarchical models using Bayesian methods and MCMC techniques.

12.5 References

Bellamy, P.H., Loveland, P.J., Bradley, R.I., Lark, R.M. and Kirk, G.J.D. (2005). Carbon losses from all soils across England and Wales 1978–2003. *Nature*, **437**, 245–248.

Yallop, A.R., Thacker, J.I., Thomas, G., Stephens, M., Clutterbuck, B., Brewer, T., and Sannier, C.A.D. (2006). The extent and intensity of management burning in the English uplands. *Journal of Applied Ecology,* **43 (6),** 1138–1148.

Vernik, T. (2005). *Factors controlling carbon loss in soils in upland Wales*. MSc thesis, Cranfield University

Verheijen, F. (2005). *On-farm benefits from soil organic matter in England and Wales*. PhD thesis, Cranfield University

Bradley, R.I., (2005). *SP0546 : Soil Organic matter as a headline indicator of soil health*. Defra report

DETR (2000). *Carbon Sequestration in Vegetation and Soils*. CEH Edinburgh

WinBugs software 1996-2004

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

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13.1 Overview of models under development

Several models are being developed for soil and plant carbon. Here we give an overview of current model development in the UK with relevance to soil and vegetation carbon. Although these models all describe the plant soil system, their purposes are quite different, so the models will describe processes in different ways. Here we give an overview of these models.

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 PFT's 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. Current work on the model includes introducing an age structure in the vegetation and introducing a nitrogen cycle. 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). Recent 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 and grassland. The soil C and N module of ECOSSE is being coupled to JULES.

RothC-Biota was developed specifically for the carbon inventory. The purpose of this model was to combine two well-developed models to calculate carbon stocks for the carbon inventory. The two models were RothC (Jenkinson *et al*., 1987; Coleman and Jenkinson, 1999) for the belowground carbon, and Biota (Wang and Polglase, 1995) for the aboveground carbon. However, the original Biota could only handle unmanaged trees, so extensive development followed; (Sozanska-Stanton *et al*., 2002; Brown *et al*., 2003; Brown *et al*., 2004). At present the model has three vegetation types: grasses, trees and crops, and fine-tuning of these parameters is in progress. However, the description of the plant types is simpler than in JULES, and plant functional type distribution is prescribed rather than estimated within the model.

13.2 Model testing

See JULES home page (http://www.jchmr.org/jules/index.html) for information on past and current developments of JULES, and evaluation.

The ECOSSE model is still being tested using data from field experiments from the UK and elsewhere. An example from a field site in Finland (Regina *et al.*, 2004) is shown in Figure 13-1.

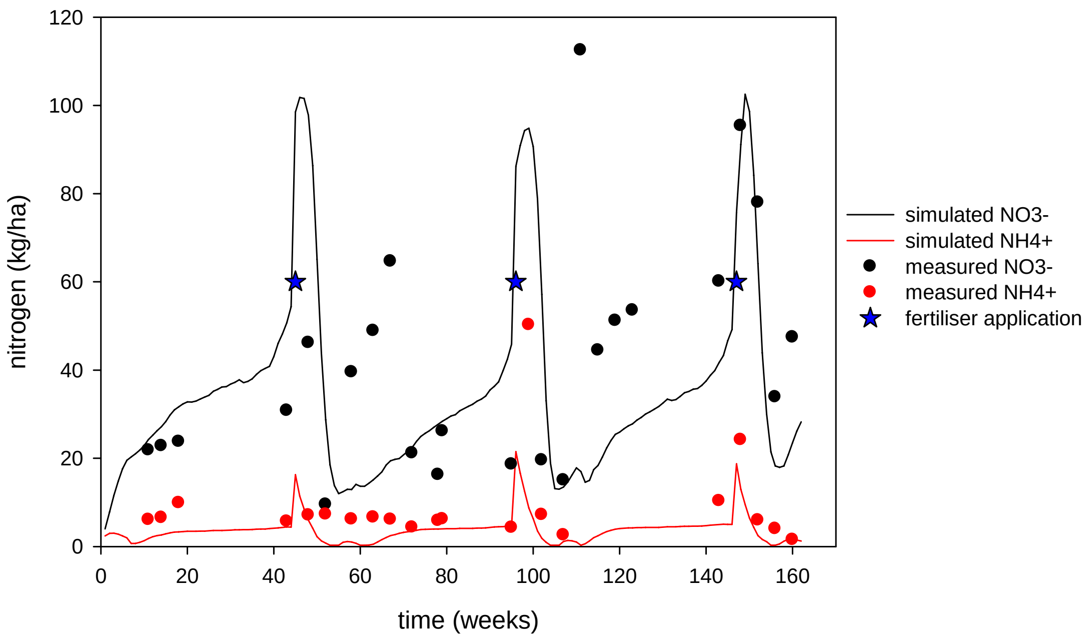

Figure 13-1: Measured and simulated mineral nitrogen in spring barley fields in southern Finland (60°49'N, 23°01'E). Time of fertiliser application is indicated.

RothC-Biota has not been extensively tested yet, although some results of preliminary tests of earlier versions of the model have been presented in previous reports (Sozanska-Stanton *et al.*, 2005; Sozanska-Stanton and Smith, 2006). We have also performed a test of the model at a grassland site in Scotland, Sourhope (Figure 13-2). Clearly, more calibration is necessary, but the results seems to indicate that model is rather insensitive to year to year variations in climate, and may need some fine tuning to respond more accurately.

We have also started comparing the results from RothC-Biota to those of JULES. Such a comparison is difficult because JULES calculates which combination of plant functional types that will be present in each time step, whilst in RothC-Biota one plant cover type must be prescribed. Furthermore, the way productivity is calculated is different. Whilst JULES calculates NPP directly, RothC-biota calculates an unlimited NPP first, and then applies various limitations to it. Tests are still preliminary, but Biota and JULES appear to predict similar values for biomass carbon, but the patterns of productivity are quite different (Figure 13-3). Biota seems to predict higher GPP and higher respiration. Further work is underway to understand the differences.

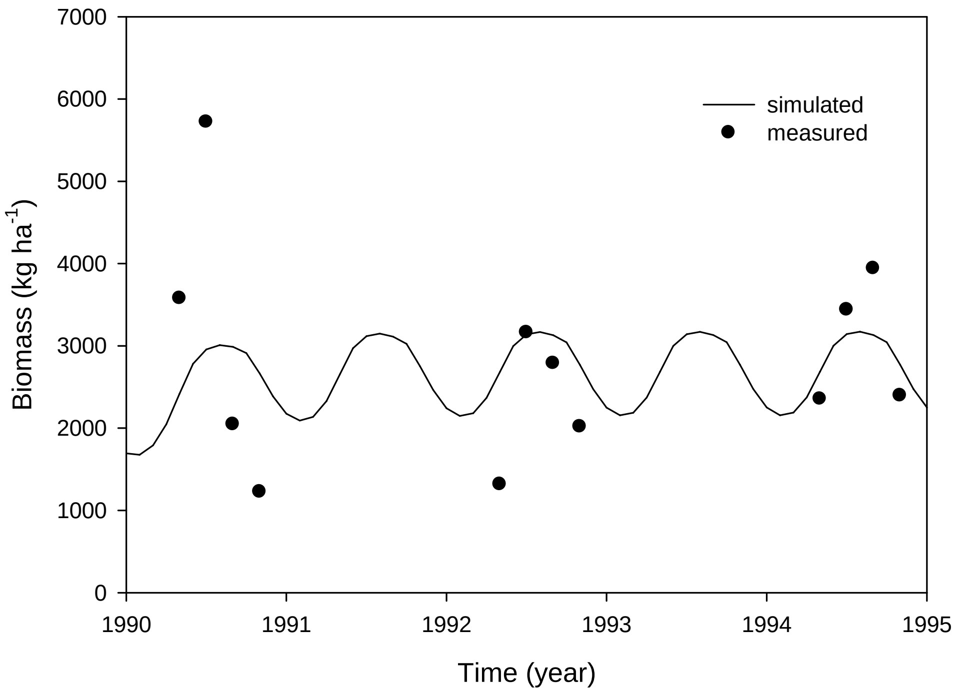

Figure 13-2: Grass aboveground biomass simulated by RothC-Biota compared to measured data from Sourhope, Southern Scotland (Data from Marriott, unpublished).

13.3 Next steps

Further work will be on parameterisation of RothC-Biota for different vegetation types. Plant cover types will be selected to be generic, and to use categories that can be distinguished on a large scale. The plan is to include managed and unmanaged grassland, broadleaf and conifer forest, spring and winter cereals and root crops. The model will then be further tested against data and other models. The model will be run for Britain and the results will be compared to the values from the carbon inventory.

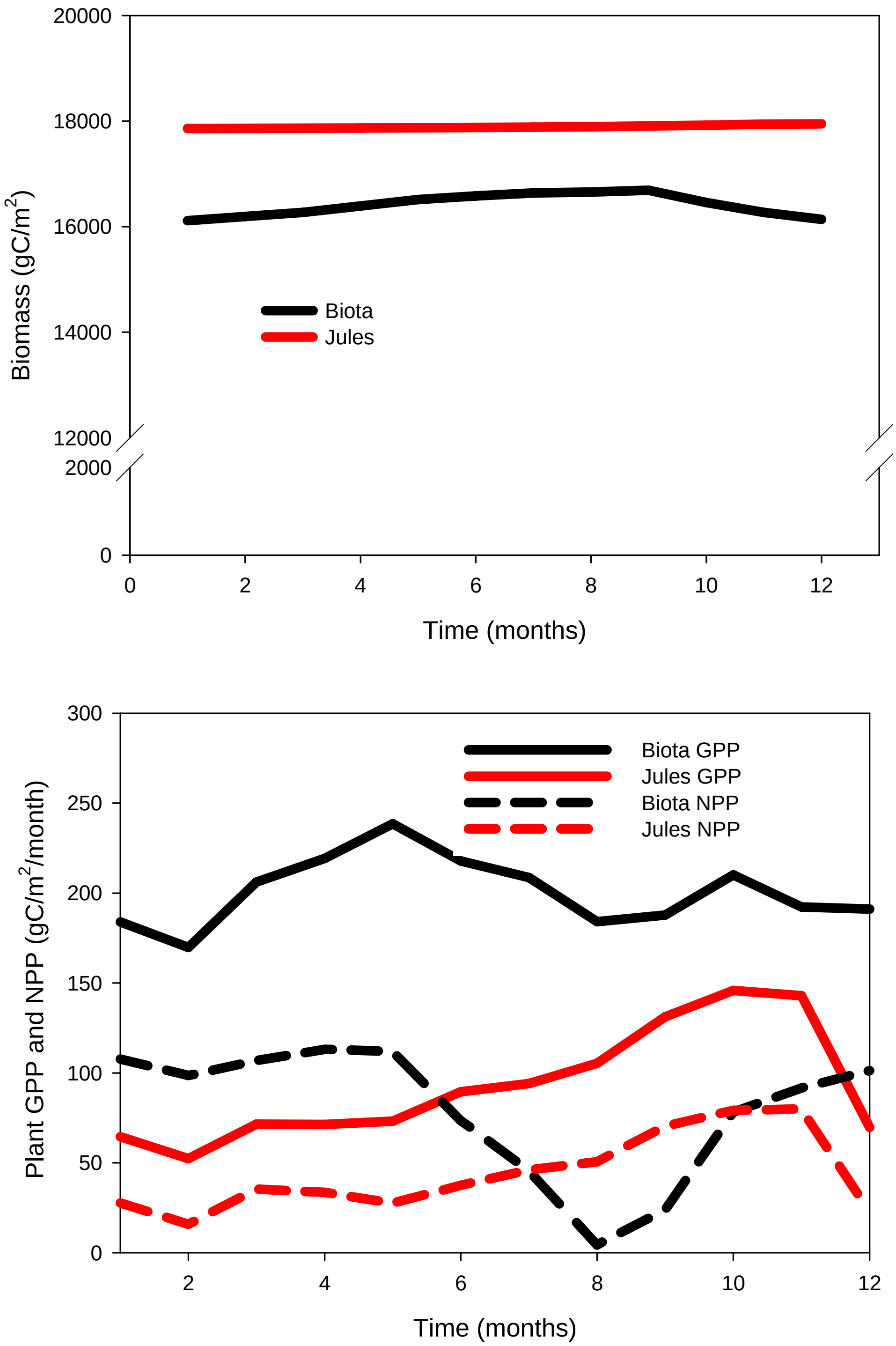

Figure 13-3: Total vegetation carbon, GPP and NPP simulated by RothC-Biota and JULES for Loobos coniferous forest flux tower site, The Netherlands (52°10'4.29"N, 5°44'38.25"E).

13.4 References

Best, M. (2005). JULES Technical Documentation. Hadley Centre.

Bradbury, N.J., A.P. Whitmore, P.B.S. Hart, and D.S. Jenkindon. (1993). Modelling the fate of nitrogen in crop and soil in the years following application of ^{15}N-labelled fertilizer to winter wheat. *Journal of Agricultural Science* **121**, 363-379.

Brown, T.A.W., R. Milne, P. Smith, and M. Sozanska-Stanton. (2003). Adding vegetation Carbon to the RothC Soil Carbon Model. p. 5:1-5.8. *In* R. Milne (ed.) *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*. Defra, Global Atmosphere Division, CEH, Edinburgh.

Brown, T.A.W., R. Milne, P. Smith, and C. Zhang. (2004). Adding Vegetation Carbon to the RothC Soil Carbon Model. p. 4.1-4.16. *In* R. Milne, and D.C. Mobbs (eds.) *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*. Defra, Global Atmosphere Division, CEH, Edinburgh.

Coleman, J.S., and D.S. Jenkinson. (1999). *ROTHC-26.3 Model description and windows users guide*. IACR – Rothamsted, Harpenden Herts AL5 2JQ.

Cox, P.M., R.A. Betts, C.B. Bunton, R.L.H. Essery, P.R. Rowntree, and J. Smith. (1999). The impact of new land surface physics on the GCM simulation of climate and climate sensitivity. *Climate Dynamics* **15**:183-203.

Jenkinson, D.S., P.B.S. Hart, J.H. Rayner, and L.C. Parry. (1987). Modelling the turnover of organic matter in long-term experiments at Rothamsted. *INTECOL Bulletin* **15** 1-8.

Regina, K., E. Syvasalo, A. Hannukkala, and M. Esala. (2004). Fluxes of N_2O from farmed peat soils in Finland. *European Journal of Soil Science* **55**:591-599.

Smith, P., Smith, J.U., Flynn, H., Killham, K., Rangel-Castro, I., Foereid, B., Aitkenhead, M., Chapman, S., Towers, W., Bell, J., Lumsdon, D., Milne, R., Thomson, A., Simmons, I., Skiba, U., Reynolds, B., Evans, C., Frogbrook, Z., Bradley, I., Whitmore, A., Falloon, P. (2007). *ECOSSE: Estimating Carbon in Organic Soils - Sequestration and Emissions. Final Report*. SEERAD Report. ISBN 978 0 7559 1498 2. 166pp.

Sozanska-Stanton, M., and P. Smith. (2006). RothC-BIOTA v05 plant-soil turnover model. p. 7.1-7.21. *In* R. Milne, and D.C. Mobbs (eds.) *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*. Defra, Global Atmosphere Division, CEH, Edinburgh.

Sozanska-Stanton, M., P. Smith, R. Milne, and T.A.W. Brown. (2002). Linking Soil and Vegetation Carbon in Dynamic Models. p. 127-137. *In* R.Milne (ed.) *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*. Defra, Global Atmosphere Division, CEH, Edinburgh.

Sozanska-Stanton, M., C. Zhang, T.A.W. Brown, R. Milne, and P. Smith. (2005). RothC-BIOTA v05 plant-soil C turnover model - parameterisation and evaluation. p. 9.1-9.14. *In* R.Milne, and D.C.Mobbs (eds.) *UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities*. Defra, Global Atmosphere Division, CEH, Edinburgh.

Wang, Y.P., and P.J. Polglase. (1995). Carbon Balance in tundra, Boreal forest and humid tropical forest during climate-change - Scaling-up from leaf physiology and soil carbon dynamics. *Plant Cell Environ*. **18**, 1226-1244.

14. Approaches to incorporate the effects of climate change and land use change in LULUCF projections (WP 2.11)

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14.1 Introduction

The impact of changes in the environmental drivers (climate, nitrogen deposition and CO_2) upon the LULUCF projections has not been considered in previous inventory contracts (Milne *et al.* 2003). However, recent research has shown that C-sinks in European forests have been affected by 20th century changes in climate, atmospheric CO_2 and particularly nitrogen deposition, and that changes in these environmental drivers will continue to affect carbon budgets(e.g. van Oijen *et al*. 2004 and in press). In order to include the effects of climate change (and other indirect factors), mechanistic models are needed which represent the processes which are actually affected by these changes (principally photosynthesis, respiration, growth and decomposition), and that include the effects of land use change and land management. Here, we propose to apply two such models (both developed at CEH Edinburgh) to the UK at a 20km grid scale, to estimate the total flux and the components attributable to direct and indirect factors. The first simulates forest growth influenced by stand management (BASFOR)); (the second is a dynamic global vegetation model linked to global climate models (GCMs) (HyLand). Using these models, we will perform simulations with and without climate change to calculate the effect on LULUCF carbon fluxes. We can thereby 'factor out' the component of the LULUCF flux which results from anthropogenic climate change. We will then repeat this for other the indirect factors - CO_2 and nitrogen deposition and can account for interactions using a partial factorial design.

14.2 Methods

14.2.1 BASFOR methodology - afforestation

This work builds on development of BASFOR in the previous inventory contract (van Oijen *et al* 2005) to determine whether robust relationships between environmental drivers and carbon storage can be identified that can be used to improve the simple semi-empirical forest model CFLOW. BASFOR is a suitable tool for this work because it is of sufficient complexity to account for the different environmental drivers in a mechanistic way, while still being fast enough to allow the large number of runs required by the Bayesian calibration.

BASFOR will be calibrated using data collected in the UK plots of the Intensive Forest Monitoring Network (Level II). A range of data-sets are collected, including growth, foliar chemistry, soil chemistry and characteristics, leaf area index and phenology, will be processed and made available. These data, augmented by data from FR’s Permanent Measurement plot network as appropriate, will provide input to Bayesian calibration of the model.

1. Parameterize BASFOR using new data from the Forestry Commission using Bayesian calibration
2. Uncertainty analysis to determine whether the effects of the environmental drivers can be captured in simple, robust algorithms for incorporation in CFlow.
3. Identify the most suitable algorithms for representing the nitrogen cycle in Hyland.

14.2.2 HyLand methodology – all land use change

As the HyLand model has been applied previously at the global scale, the main computational procedures are in place.

1. Assemble and format climate data for the historical period for the UK 20 km grid, and extend to 2100 using the UKCIP projections for climate.
2. Calculate land use change matrices for the 20 km grid for the historical period, based on previous CEH work, and extend to 2100 using the SRES scenario projections, as down-scaled in the EU ATEAM (Rounsevell *et al*. 2006) project.
3. Calibrate the model to correctly predict the UK vegetation and soil carbon stocks for the near-present day (to 2020).
4. Perform full simulations to estimate the LULUCF flux from a pre-history "spin-up" period to 2100. Long simulations are necessary, because of the long time scale of soil carbon turnover, but interest in the results will be focussed on 1990 to 2020. An incomplete factorial experimental design will be used, to allow the effects of climate change and CO_2 on the LULUCF flux to be quantified (as in Levy *et al*. 2004).

14.3 Progress to date

The bulk of this work is planned for winter 2007/08, but the initial task is to produce the input data sets required by the two models for these simulations. The key inputs are land use, land use change, climate, soil nitrogen, and nitrogen deposition, all on a 20km grid covering the UK. This is largely complete for climate, and relatively straightforward for land use change and nitrogen deposition. An MSc student from University of York (Andrew Clark) will work on this project for three months from June 2007 as a summer placement, and is expected to complete the input data sets and perform preliminary model runs. The simulations are likely to be repeated later in the project, when the estimated land use change matrices change as data analysis proceeds in related work packages.

14.4 References

Levy, P.E., Cannell, M.G.R. and Friend, A.D. (2004) Modelling the impact of future changes in climate, CO_2 concentration and land use on natural ecosystems and the terrestrial carbon sink. *Global Environmental Change-Human and Policy Dimensions*, 14, 21-30.

Meir P., Conen, F. and Nagy, L. (2003) Baseline survey of carbon stocks at selected SFA sites in Scotland. Interim report for 2003, covering measurements made at three sites: Abernethy Forest Reserve, Glen Sherup and Darrochwids. Unpublished report to SFA/BP/ECCM, Edinburgh.

Milne R.M. *et al.* (2003). UK Emissions by Sources and Removals by Sinks due to land Use, Land Use Change and Forestry Activities. Report, April 2003, DEFRA Contract EPG1/1/160.

Rounsevell M.D.A., Register I., Araùjo M.B. *et al.* (2006) A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems and Environment* (in press).

van Oijen, M., Cannell, M.G.R. & Levy, P.E. (2004). Modelling biogeochemical cycles in forests: state of the art and perspectives. In: Andersson, F., Birot, Y. & Päivinen, R. (Eds.), *Towards the Sustainable Use of Europe's Forests – Forest Ecosystem and Landscape Research: Scientific Challenges and Opportunities.* EFI Proceedings No. 49, European Forest Institute: 157-169.

van Oijen, M., J. Rougier and R. Smith (2005). Bayesian calibration of process-based forest models: bridging the gap between models and data. *Tree Physiology*. 25:915-927.

van Oijen, M., Ågren, G.I., Chertov, O.G., Kellomäki, S., Komarov, A., Mobbs, D.C. & Murray, M.B. (in press). Evaluation of past and future changes in European forest growth by means of four process-based models. In: *Causes and Consequences of Forest Growth Trends in Europe - Results of the RECOGNITION Project*. Eds. T. Karjalainen and A. Schuck. Brill, p. Chapter 4.4.

15. Inventory projections of harvested wood products (WP 2.12)

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15.1 Overview of HWP accounting

The proposal for keeping inventories of carbon retained in wood products has resulted in discussions about how the reporting and accounting should be conducted (Matthews *et al*., 2007). In 1998, a meeting in Senegal (see Brown *et al*., 1998; Lim *et al*., 1999) outlined three possibilities for carbon reporting methods beyond the simple 'IPCC default' approach mentioned above. The 'atmospheric flow approach' would report actual carbon flows to and from the atmosphere at the time and place that they physically occurred. The 'stock change approach' would report actual stocks of carbon as wood is harvested, utilised and disposed of. The 'production approach' would also report changes in wood-based carbon stocks, with the difference that all stocks would remain attributed to the point of origin (i.e. to the party owning the forest that produced the harvested wood), regardless of where the wood products happened to reside. A more recent fourth approach, the 'simple decay approach' reports actual carbon flows to and from the atmosphere like the atmospheric flow approach but, similarly to the production approach, the emissions remain attributed to the party owning the forest that produced the harvested wood.

Table 15-1 makes clear that the choice among these accounting possibilities makes a considerable difference to parties that are major importers or exporters of wood products. Debate continues between parties as to which reporting method to adopt.

Any system for modelling harvested wood products (HWP) carbon stocks needs to be flexible enough to work with any of the proposed reporting approaches.

15.2 Development of FC forecasts

Following the conclusion of the 2005 Production Forecast exercise (see chapter 7), the Forestry Commission commissioned Forest Research to prepare a plan for the development of an upgraded and improved FC forecast system. This system has been designed to facilitate many types of forecast, including estimates of current and future carbon stocks in wood products. Key features of the plan include:

- Better integration of forecasts for FC and privately owned woodlands to achieve greater consistency.
- Improvements to the transparency of data and assumptions underpinning forecast results.
- Recognition of the wider requirements for forecast outputs such as estimates of standing volume, carbon stocks and woodfuel availability.

The plan recommends an approach to development of the system is based on six key principles:

- Maximise use/application of existing models
- Maximise reliance on proven methodologies
- Maximise utilisation of existing sources of forest information
- Specify an essential kernel system at outset

- Incremental development from kernel to address additional requirements progressively
- ‘Future-proofing’ of system structure.

An overview of the forecast system design is given in Figure 15-1, which also shows how different modules will be integrated incrementally into the system. Among the key system components are the ASORT, BSORT and DSORT models (Matthews and Duckworth, 2005), and an extension to a forest and wood products carbon accounting module, CSORT.

Table 15-1: Total greenhouse gas emissions and the contributions due to land use, land-use change and forestry (LULUCF) and harvested wood products (HWP), by country. Values are in MtC equivalent emissions or as the percentage of total emissions in the base year (1990) without emissions or sinks due to LULUCF. Base year for emissions reported as due to LULUCF is also 1990, however for HWP emissions the base year is 2000. (Adapted from Pingoud *et al*., 2003.)

Country	**National greenhouse gas emissions (MtC equivalent per year)**			**Percentage contribution due to HWP**		
	Total (without LULUCF or HWP)	LULUCF	HWP (stock change approach[1])	Stock change approach[1]	Atmospheric flow approach[1]	Production approach[1]
Australia	116.0	21.3	-0.6	-0.5	-0.1	-0.5
Austria	21.1	-2.5	-0.8	-4.0	-4.3	-2.4
Belgium	38.9	-1.6	-0.4	-1.0	0.9	-0.5
Canada	165.6	-16.8	-2.5	-1.5	-15.1	-5.6
Denmark	18.9	-0.2	-0.5	-2.7	3.3	-0.2
Finland	21.0	-6.5	-0.6	-3.1	-30.6	-5.8
France	152.5	-15.3	-1.8	-1.2	-0.5	-1.4
Germany	333.5	-9.2	-3.0	-0.9	-0.6	-1.0
Greece	28.6	0.4	-0.2	-0.6	1.5	0.0
Ireland	14.6	-0.0	-0.0	-1.6	-0.4	-1.7
Italy	142.0	-6.4	-1.8	-1.3	2.6	-0.3
Japan	340.0	-22.9	-0.3	-0.1	2.4	0.4
Netherlands	57.4	-0.4	-0.3	-0.5	2.3	-0.2
New Zealand	30.0	-6.0	-0.3	-1.6	-12.8	-5.5
Norway	14.2	-2.7	-0.2	-1.4	-2.7	-0.4
Portugal	17.7	-1.0	-0.3	-1.8	-4.1	-1.0
Spain	78.1	-8.0	-1.5	-1.9	2.7	-0.5
Sweden	19.2	-5.5	-0.3	-1.5	-26.1	-4.0
UK	202.5	2.4	-0.9	-0.5	2.0	-0.4
USA	1672.0	-299.4	-19.8	-1.2	-0.7	-0.8

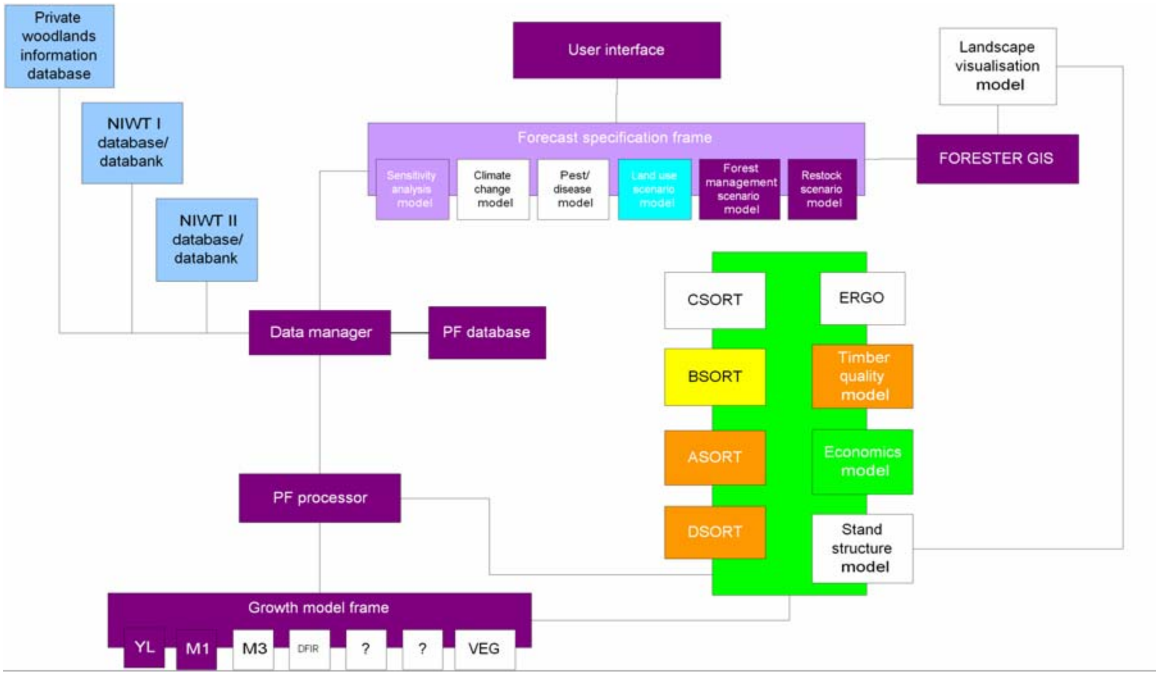

Figure 15-1: System diagram for proposed FC forecast methodology. Colours indicate stages in the system build. Modules in the diagram that are not coloured are not covered by the development plan as currently proposed.

The proposed forecast system, integrated with ASORT-DSORT has the capability to generate consistent estimates of carbon stocks and stock changes for the British forest estate and for home-grown HWP. This permits reporting of HWP carbon as envisaged by the simple decay and production approaches. Handling of the stock change and atmospheric flow reporting approaches could be achieved through inclusion of an additional module in the forecast system to receive and process statistics and future projections for wood imported into Britain and/or the UK.

15.3 References

Brown, S., Lim, B. and Schlamadinger, B. (1998) *Evaluating approaches for estimating net emissions of carbon dioxide from forest harvesting and wood products.* Meeting Report, Dakar, Senegal, 5–7 May, 1998. IPCC/OECD/IEA, Paris, France.

Lim, B., Brown, S. and Schlamadinger, B. (1999) Carbon accounting for forest harvesting and wood products: review and evaluation of different approaches. *Environmental Science and Policy* **2**, 207–216.

Matthews, R.W. and Duckworth, R.R. (2005) BSORT: a Model of Tree and Stand Biomass Development and Production in Great Britain. In: Imbabi, M.S. and Mitchell, C.P. (eds.) *Proceedings of World Renewable Energy Congress* (WREC 2005), 22-27 May 2005, Aberdeen, UK. Elsevier: Oxford, 404-409.

Matthews, R.W., Robertson, K., Marland, G. and Marland, E. (2007) Carbon in wood products and product substitution. In: Freer-Smith, P.H., Broadmeadow, M.S.J. and Lynch, J.M. (eds). *Forestry and Climate Change*. CAB International: Wallingford, 91-104. (In press.)

Pingoud, K., Perälä, A-L., Soimakallio, S. and Pussinen, A. (2003) Greenhouse Gas Impacts of Harvested Wood Products. *VTT Research Notes* **2189**. Espoo, Finland.

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 different pair of categories. This detail is required because the rates on 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.

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 as the Countryside Survey. These have been carried out in 1984, 1990, 1998 and another is due in 2007. They allow the land type 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 types 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 (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 "medium term" land use change matrices produced from the intermittent surveys 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. However the difference in the annual data between two years only provides *n* values. Over longer periods addition data is available from the annual data but these cannot be used directly to assess annual changes to the LUC matrix. It is therefore proposed to use a LUC matrix in which the variation in its elements are described by a simple time series model and the parameters of that model are calibrated against the annual land area data using Bayesian statistical methods.

16.2 Model structure

The 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 same use 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

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 (Equation 16-2). The probabilities of change are estimated by dividing each entry in a matrix column by the sum of the column.

$$LUC = \begin{bmatrix} {}_{AA}a & {}_{GA}a & {}_{WA}a & {}_{DA}a & {}_{OA}a \\ {}_{AG}a & {}_{GG}a & {}_{WG}a & {}_{DG}a & {}_{OG}a \\ {}_{AW}a & {}_{GW}a & {}_{WW}a & {}_{DW}a & {}_{OW}a \\ {}_{AD}a & {}_{GD}a & {}_{WD}a & {}_{DD}a & {}_{OD}a \\ {}_{AO}a & {}_{GO}a & {}_{WO}a & {}_{DO}a & {}_{OO}a \end{bmatrix}$$

Equation 16-2: *a* is area changing between land types or remaining unchanged. The sum of the matrix columns give the initial areas for Arable (${}_{A}A_{t-1}$), Grassland (${}_{G}A_{t-1}$), Woodland (${}_{W}A_{t-1}$), Developed (${}_{D}A_{t-1}$) and Other Land (A^{O}_{t-1}) *respectively*

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 (Equation 16-3) 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.

$$A_t = pA_{t-1}$$
$$A_t = p^n A_{t-n}$$

Equation 16-3: Probability of change of land use over many years using matrix multiplication.

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. In principle it would be possible to have every matrix element change every year but the amount of data required to construct this is simply unavailable in the UK at the moment. An alternative approach is to model the matrix element variation using a simple time series model. Each matrix element in such a model would have an initial value that would then change with time but would retain some memory of previous values. A stochastic element is also introduced at each time step. 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. The equation for an example transition, Arable to Grassland, is shown by Equation 16-4. For each LUC matrix transition element where variation is significant two additional parameters are required over the assumption of constant change probability. The two parameters are that controlling memory of past values and the variance of the random process used to introduce stochastic variability at each step.

$$_{AG}\, p_t = {}_{AG}\, r \; {}_{AG}p_{t-1} + {}_{AG}\, e_t$$

Equation 16-4: Simple model of variation $_{AG}p$ the probability of land changing from arable to grassland. $_{AG}r$ is a constant that controls the "memory" of past change. $_{AG}e$ is a zero mean random process with constant variance that controls external variability introduced to the parameter. p is a constant where r = 1.

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 therefore chosen as the 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.

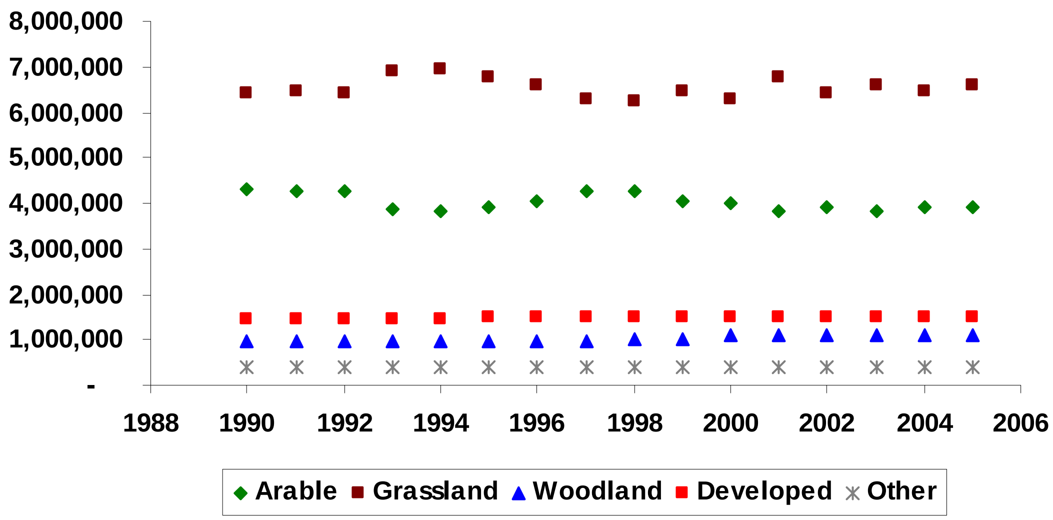

Figure 16-1: Published areas of land use in England. Area of Other land estimated by difference of sum of Arable, Grassland, Woodland and Developed from total area of England.

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 (Table 16-1).

Table 16-1: Land use change matrix for land in England for period 1990 to 1998. Units are hectares. 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 16-2: Probability of land use change in England between 1990 and 1998

From To	Arable	Grassland	Woodland	Developed	Other
Arable	0.893	0.088	0.003	0.003	0.000
Grassland	0.097	0.887	0.050	0.019	0.000
Woodland	0.006	0.013	0.939	0.012	0.000
Developed	0.004	0.012	0.007	0.966	0.000
Other	0.000	0.000	0.000	0.000	1.000

Table 16-3: Annual probability of land use change in England on average over period 1990 to 1998. Calculated as 1/8th power of matrix in Table 16-2.

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 modelled 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. It therefore proposed to use Bayesian methods to calibrate the matrix elements (and time series parameters where these are used) 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 Markov Chain Monte Carlo 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.

The model described above 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 has been assumed that the matrix is constant over the period 1990 to 2005 for initial testing and that the annual area data have an uncertainty of +/- 100,000 ha. A full execution of the MCMC procedure to likelihood convergence has not yet been carried out but a test run for 5000 different sets of probability elements starting with those from Table 16-2 is illustrated in Figure 16-2.

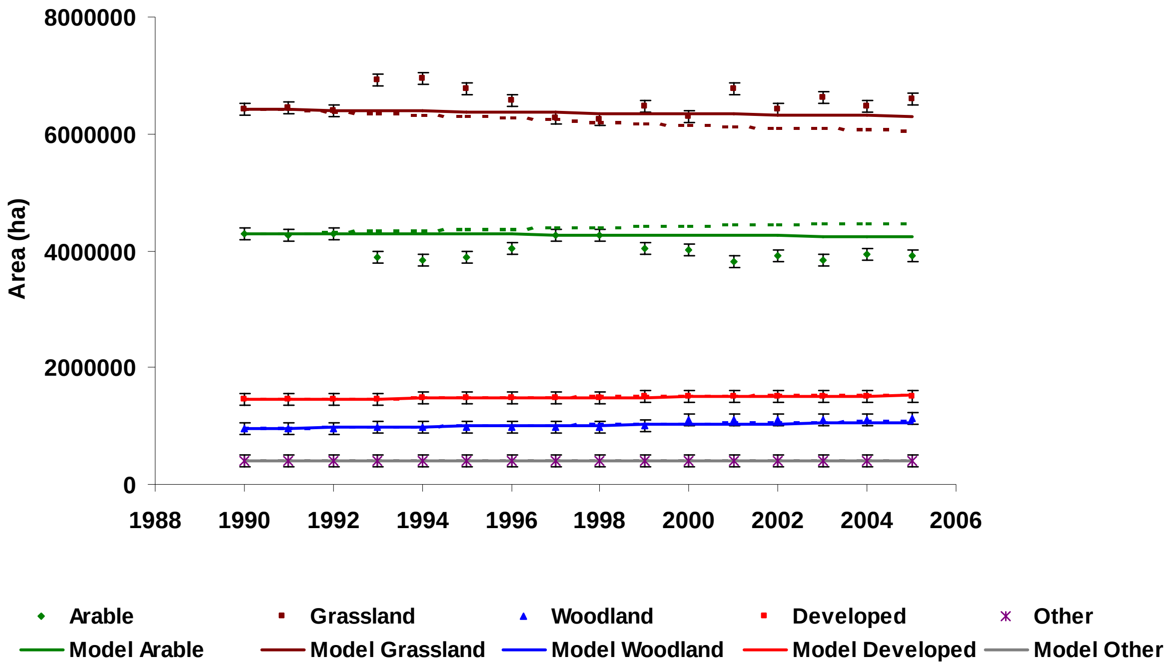

Figure 16-2: Preliminary testing of Bayesian calibration of constant land use transition matrix model for England. Graph shows trend in annual areas of land use estimated from probability matrix with values from Countryside Survey before (dotted line) and after Bayesian calibration (solid line) compared to published annual data (points).

16.5 Next steps

- Include stochastic model for matrix elements into Excel spreadsheet
- Calibrate time variable model against 1990 to 2005 English annual data

16.6 References

DCLG (2006) *Land use Change Statistics* http://www.communities.gov.uk/index.asp?id=1146601

FC (2006) *Forestry Statistics 2006*, http://www.forestry.gov.uk/website/ForestStats2006.nsf/byunique/index_main.html

IPCC (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Institute for Global Environmental Strategies (IGES) for the Intergovernmental Panel on Climate Change, Kanagawa, Japan.

MLC (1986). *Monitoring Landscape Change*. Report prepared by Hunting Surveys & Consultants Ltd for Department of the Environment and the Countryside Commission.

van Oijen, M., Rougier, J. and Smith, R. (2005) Bayesian calibration of process-based forest models: bridging the gap between models and data. *Tree Physiology*, **25**, 915 – 927.

17. Verification approaches (WP 2.14)

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The objective of this work package 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.

The first annual workshops has been delayed because of related CarboEurope meetings and discussions about the establishment of an infrastructure for a Europe-wide GHG-carbon monitoring system based also on models, flux towers and atmospheric measurements. This is mentioned here because it is highly relevant and synergistic with the present project. A first proposal for the preparatory phase of a European Integrated Carbon Observation System (ICOS) has been co-ordinated and submitted to the European Commission for funding by Philippe Ciais of the Laboratoire des Sciences du Climat et de l'Environnement, a joint research unit of the Centre National de la Recherche Scientifique (CNRS) and the Commissariat à l'Energie Atomique, two major funding agencies in France. The Partners include the Universities of Tuscia (Italy), Heidelberg (Germany), Amsterdam (Netherlands), Helsinki (Finland), Edinburgh (UK) and the Max-Planck-Gesellschaft (Germany).

The success of the system depends on financial support from member states, and one of the objectives in the preparatory phase of ICOS is to seek substantial funding for the required operational infrastructure.

The observational system would provide verification of GHG fluxes for European countries, dis-aggregation of fluxes into biogenic and anthropogenic components, and identification of the fluxes associated with particular land cover. The data and associated models would therefore enable 'what if' experimentation regarding the impact of making changes in land use.

Much relevant expertise in this area is now in the UK, and it is expected that UK funding agencies will have a major role in the success of ICOS, following the preparatory phase (2008-2012).

The first annual workshop on verification approaches within the UK is now being organised somewhat later than was planned: August 2007 rather than June 2007. By this time, the status of the ICOS bid to the European Commission is likely to be known; also the result of an attempt is being made to gain UK support from NERC.

The first annual workshop will contain these elements

- How the UK inventory is derived
- What Earth Observation can tell us

- Use of atmospheric measurements to verify the inventory
- Modelling the fluxes- data requirements
- Use of the ICOS approach after 2012
- Optimal design of a verification system

CTCD's work on the carbon fluxes associated with forests will be reported in Nature on June 14th 2007. The report provides a new insight into the way 'the hand of man' controls the carbon sink of forests through management (deliberate by afforestation, deforestation and general disturbance) and by fertilizing the forest (inadvertent through the deposition of nitrogen). The analysis is based on a sample of European forests and also new data from N American forests. Magnani F, Mencuccini M, Borghetti M, Grace J and 17 others (2007) The human footprint in the carbon cycle of established temperate and boreal forest. Nature ***, **-**.

18. Design of Greenhouse Gas Observing Systems (WP 2.15)

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18.1 Rationale

In this section, we briefly report on work within CTCD from 2006 that contributes to verification, observing systems and remote sensing methods relevant to the DEFRA LULUCF project. This includes:

- SDGVM Model Developments and analyses
- *In situ* measurements of C pools and fluxes
- Data assimilation and C modelling

18.2 SDGVM Model Developments and analyses

18.2.1 Model Development within SDGVM

The primary Dynamic Global Vegetation Model (DGVM) for estimating that we are making use of for flux estimation is the Sheffield DGVM (SDGVM). This year's major SDGVM model developments have been concerned with tracing the dynamics of individual functional type cohorts and a completely new representation of root and soil carbon dynamics. Of particular relevance to this project are:

Fully per cohort representation

Previously, although there was a per cohort representation used for yearly processes e.g. thinning, fire and biomass accumulation, the plant physiology was only computed per functional type. The system state arrays and functional type parameters have now been restructured to provide a fully per cohort representation. This is computationally burdensome but is particularly important to model the effects of young vegetation in a realistic manner.

New soil carbon/hydrology module

This provides a detailed vertical profile of soil hydrology, organic carbon and soil mineral fractions, providing a mechanism for rooting depth to evolve over time throughout a 'realistic soil profile'(Figure 18-1 and Figure 18-2). Ultimately, this will play a major role in "natural vegetation" through competition, as well as providing a physical link from the vegetation to soil moisture. The new representation has the ability to produce both organic and mineral soils with realistic soil C contents. This is achieved by controlling the mixing of soil quantities between adjacent layers, along with the decomposition rates, representing biological activity determined by soil pH, litter quality and rock/sediment (soil) substrate.

Improved coupling between stomatal conductance, transpiration and roots

Previously, the effect of reduced soil moisture on stomatal conductance was accounted for empirically. So, the 'supply', governed by stomatal conductance and soil moisture, was not directly equated to the 'demand', governed by atmospheric conditions and stomatal conductance (Penman-Monteith equation). This has been addressed by including the Penman-Monteith equation in the system of non-linear equations used to determine assimilation, stomatal conductance and internal CO_2 partial pressure. In reality, if ‘demand’ exceeds ‘supply’ a plant may incur irreversible damage.

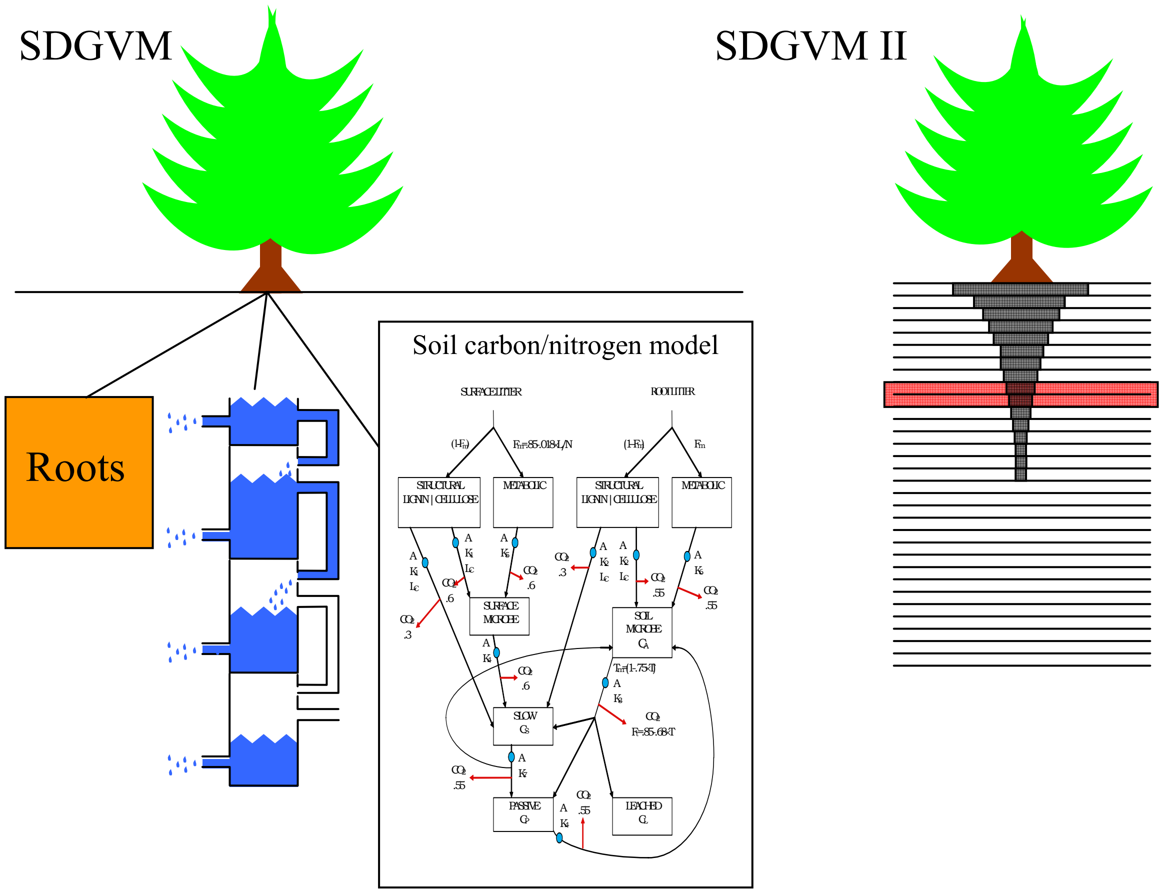


Figure 18-1: Soils representation

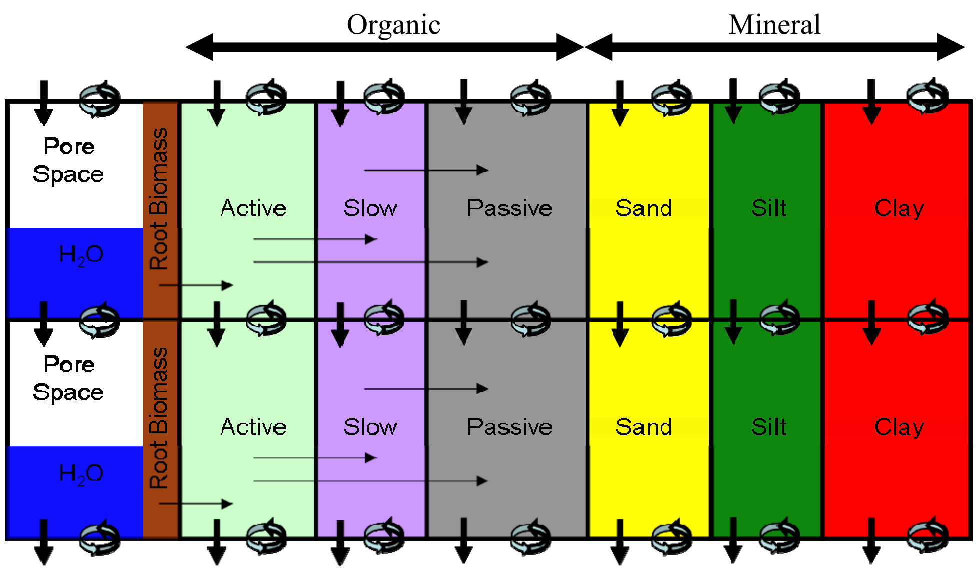


Figure 18-2: Adjacent soil layers from SDGVM II.

18.2.2 SDGVM parameter uncertainty

The work reported last year, in which we derived the uncertainty due to model parameters in SDGVM-based estimates of the England and Wales carbon flux in 2000, has been accepted for publication in the Royal Statistical Society's Journal Series A, Statistics and Society. Since then, we have been actively extending the work to incorporate uncertainty due to land cover. The previous exercise took land cover derived from LCM2000 as given, and we now account for uncertainty using a confusion matrix obtained from the Countryside Survey. This has entailed novel statistical modelling to include prior distributions for land cover and to introduce a spatial element across England and Wales. Ongoing work will propagate this uncertainty through to its implications for uncertainty in SDGVM's carbon flux estimates.

18.3 In situ measurements of C pools and fluxes

18.3.1 Characterising and reducing uncertainties in soil C stocks and fluxes, and assessing the effects on C flux models

Our research this year has addressed some key science questions, such as (i) soil carbon temperature sensitivity and potential feedback implications, (ii) soil respiration component fluxes and individual environmental responses, (iii) NEE flux methodology and modelling, (iv) restructuring existing soil carbon models for mineral and organic soils by incorporating latest science and biology, (v) advising on soils-related model uncertainty, (vi) exploring available climate and EO data (i.e. fAPAR & NDVI) for explaining global soil carbon distribution. We have successfully deployed the novel multiplexed CTCD soil respiration kit in a pine forest (Wheldrake, York) and an upland moorland site (Moor House, Pennines) in collaboration with CLASSIC (joint PhD). The system provided key science data and a novel mesh collar design led to important insight into soil respiration methodology and component fluxes, both with important implications for model process understanding. We have also adapted this system for continuous measurements of both respiration and NEE fluxes; this system is now deployed in the Arctic (ABACUS, NERC IPY), whereas the other system is at the research forest at Alice Holt (FR). Both systems are operated in conjunction with an eddy tower system, providing, for example, high quality soil flux data for crucial eddy night-time flux validation. Furthermore, through the purchase of a trace gas analyser unit linked to the multiplexed flux system, we can now provide break-through continuous trace gas fluxes (i.e. CO_2, CH_4 & N_2O) on peatland sites, whose vulnerability was pointed out by Bellamy *et al*. (2005). This has led to important links to the UKPopnet initiative measuring trace gas fluxes at catchment scale experimental plots (gully blocking) with strong science to policy implications. The flux work will provide a crucial component in validating and improving the newly developed CTCD soil carbon sub-model. Our strong position is reflected in numerous international collaborations such as the ESF (co-editorial of a book on soil respiration methodology), COST (action 639 "BurnOut") and research links to other EU Universities (e.g. Umea with Peter Hoegberg). A very important success was the research work by the York PhD student (Iain Hartley), resulting in major publications (Heinemeyer *et al.* in press; Hartley *et al.* in press (a) and(b)); the joint CLASSIC PhD student will follow suit. We also initiated major outreach and knowledge transfer with a CTCD exhibit "The Breathing Forest" at the Royal Society summer science exhibition (July 2006) and contributed to an ABACUS science field workshop.

a) The year-long experimental work at Wheldrake Forest was exceptional and produced a major publication (Heinemeyer *et al.* in press) on field separation of soil CO_2 fluxes into three components due to roots, soil heterotrophes and mycorrhizal hyphae (Figure 18-3). Interestingly, the latter did not respond to soil temperature, as found previously (Heinemeyer *et al.* 2006); we are operating such a system at the NERC ABACUS IPY project at Abisko.

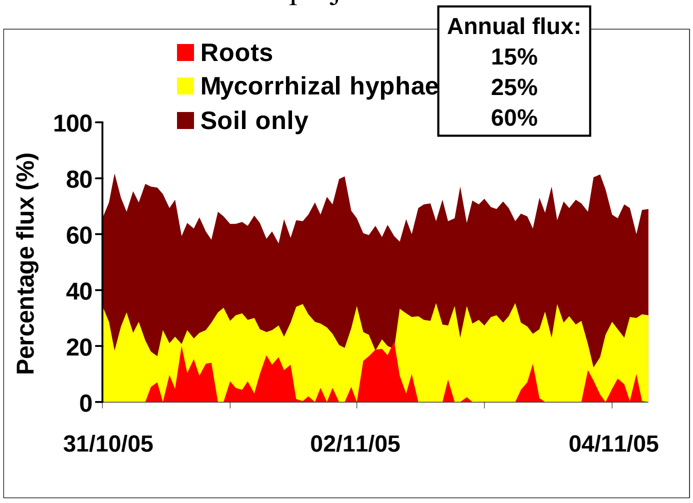


Figure 18-3: An extract from the separated soil respiration fluxes (percentage fluxes based on hourly measurements) at Wheldrake forest (pine forest) during a period in November 2005 (annually till March 2006). Note the low root but high mycorrhizal hyphal flux contribution, even annually; separation was achieved using a novel mesh collar design. This work was possible though a successful bid into the NERC CEB, enabling the construction of a multiplexed continuous soil respiration monitoring system.

b) The joint CTCD/CLASSIC CO_2 flux monitoring at the peatland site at Moor House was very successful and produced the first highly detailed soil respiration data for any UK peatland site (Figure 18-4). Importantly, hourly soil fluxes were obtained using surface collars, avoiding flux losses by cutting roots with collar insertion (see (c)). These data (NEE eddy and soil fluxes) will be crucial for model evaluation (new CTCD soils sub-model and the ECOSSE model with Pete Smith, Aberdeen). Data will be submitted to Global Biogeochemical Cycles.

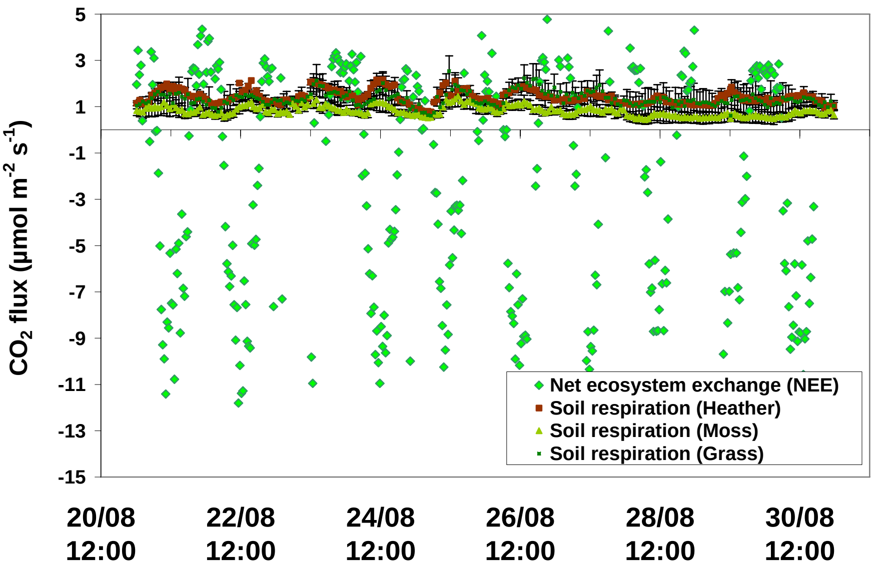


Figure 18-4: A 10-day extract from hourly Moor House NEE CO_2 fluxes (heather moorland) with soil respiration fluxes for three different vegetation types (heather, grass, moss) during a period in August 2006. The soil respiration fluxes, measured with surface collars, are around 50% of night time NEE fluxes (ecosystem respiration). Note the very high carbon uptake that could be observed during the entire very warm and sunny summer of 2006.

c) Our field work further demonstrated at two contrasting sites (Wheldrake pine forest and Moor House peatland) that conventional collar insertion of only a few cm (commonly insertion is to about 10 cm) will lead to dramatic long-term underestimation of soil CO_2 fluxes (Figure 18-5), mainly by cutting through the surface fine root and mycorrhizal layer. This has implications for global soil respiration estimates and model evaluation.

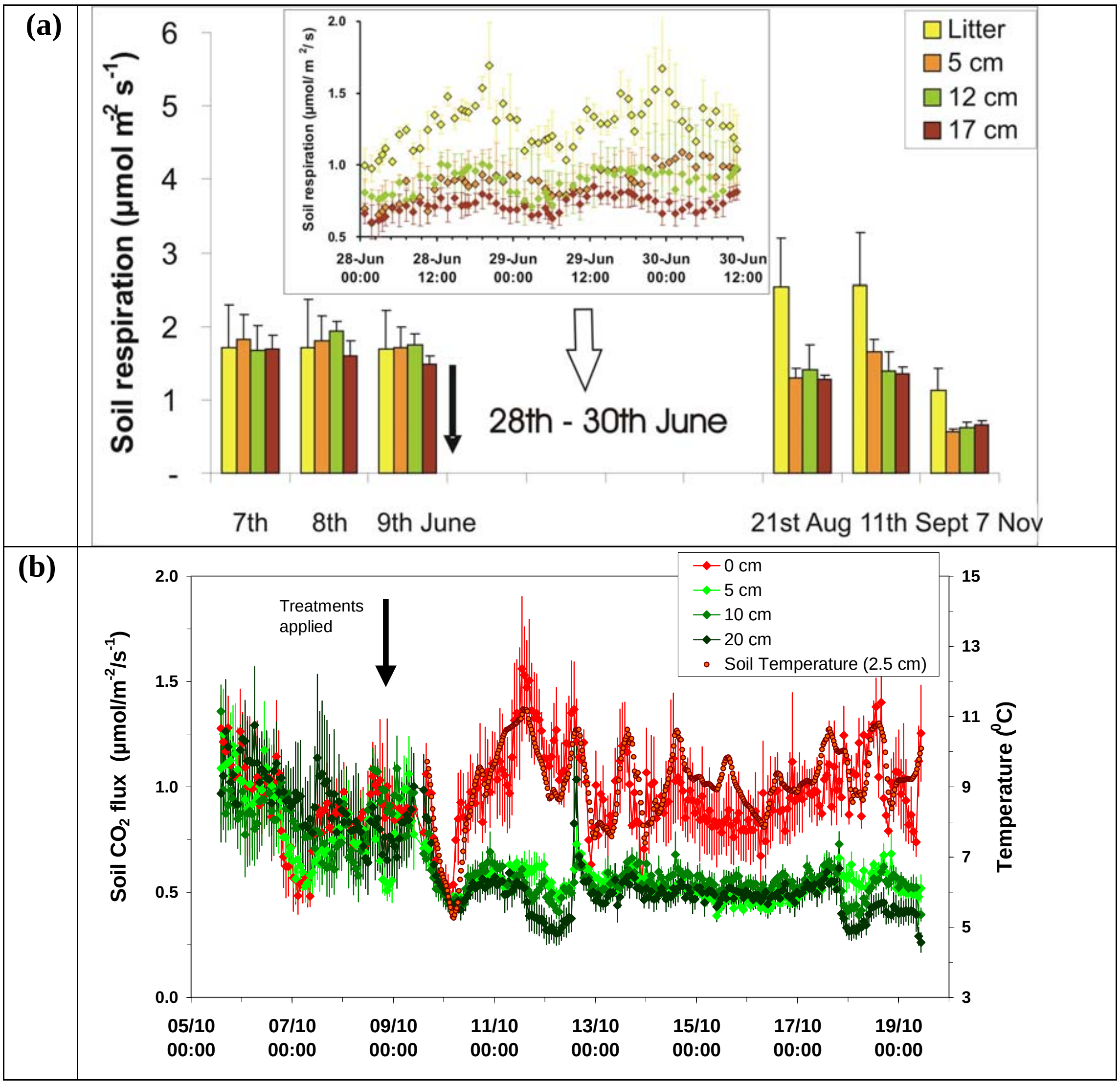


Figure 18-5: The effect of collar insertion to different soil depths on measured soil CO_2 fluxes in 2006; (a) pine forest near York and (b) heathland site at Moor House. Note the dramatic decrease in measured soil respiration after collar insertion (black arrows), even at the low insertion depths (i.e. 5 cm). The inset in a) shows hourly fluxes; both measurements included a pre-treatment period (period left of arrow).

d) The deployment of 12 soil respiration chambers at the eddy tower site at Alice Holt (since March 2007) has already produced excellent data (Figure 18-6). FR staff are available at the site and data are transferred weekly via FTP. These will be used for model improvements and development within FR/CTCD.

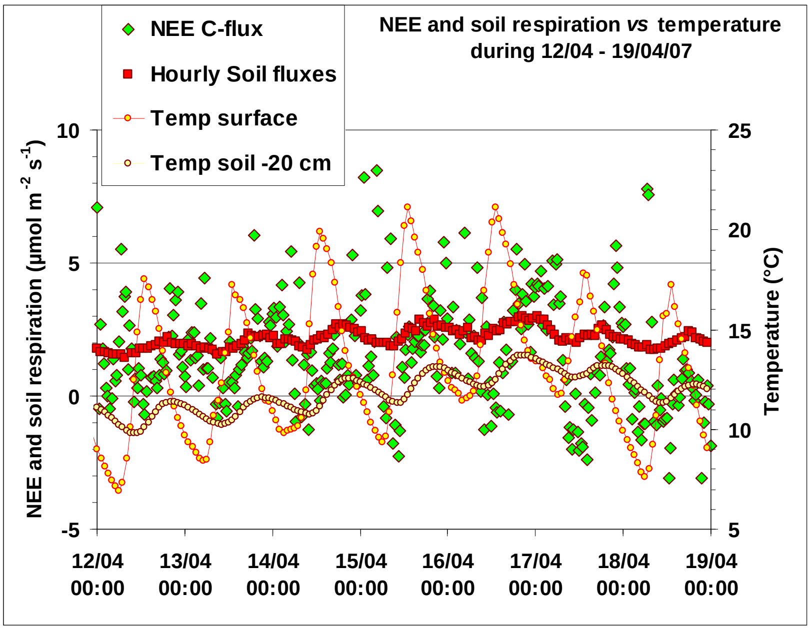


Figure 18-6: Extract from the Alice Holt (mixed oak forest) eddy and soil respiration fluxes during a weeklong period in April 2007. Hourly eddy flux data are for the same period as the soil respiration fluxes, and are about 50% of night time ecosystem respiration (i.e. night time eddy fluxes). Note how high the air and soil temperatures are (possibly heading for an interesting drought year) and the net CO_2 uptake during the day (i.e. negative NEE) just starting to kick in after observed bud burst (around 10th April).

e) A groundbreaking development was the successful adaptation of the soil respiration system for low vegetation (e.g. grassland) NEE flux work. We finished a joint CTCD/ABACUS experiment, showing that the system actually can measure NEE fluxes very accurately (Figure 18-7) and compared C-stock inventory to the C-flux based approach. The system is now deployed in the Arctic (ABACUS). The findings will be submitted to Soil Biology & Biochemistry.

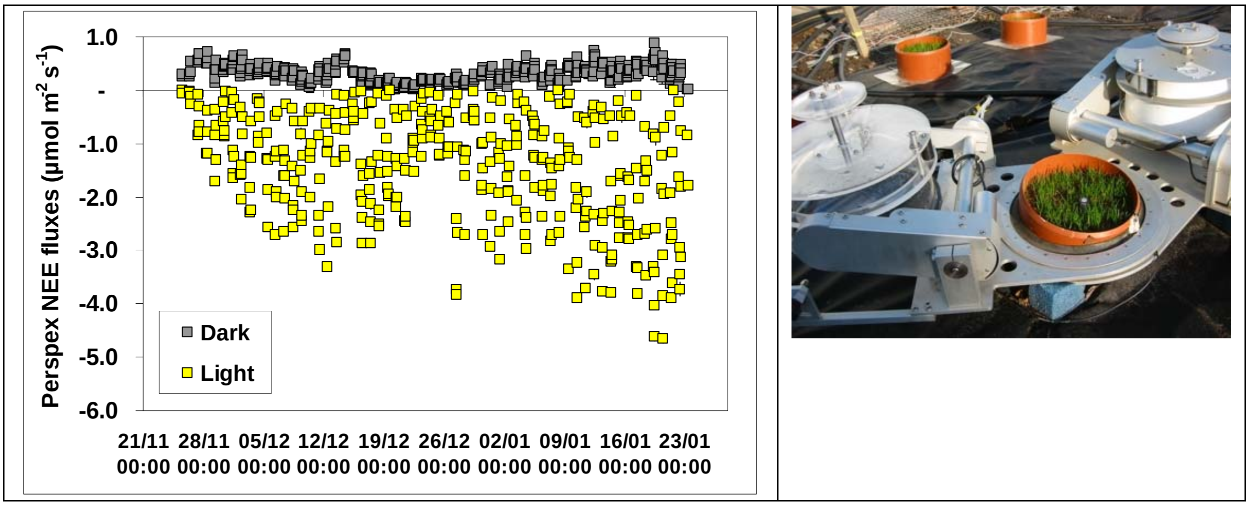
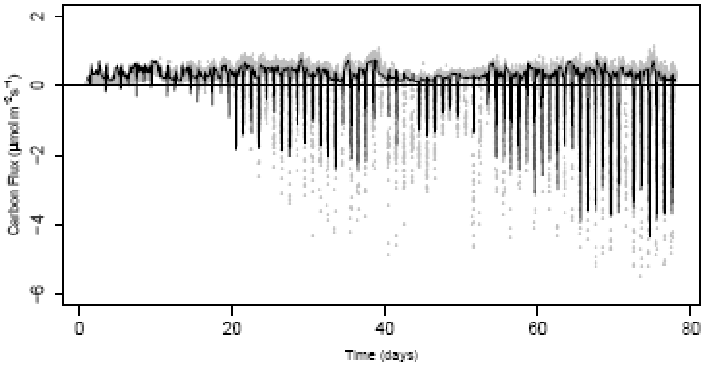


Figure 18-7: Data from the York multiplexed and continuous monitoring soil level NEE chamber system. Shown are hourly CO_2 fluxes from dark respiration (grey) and clear NEE perspex (yellow) chambers (see picture). Note the high net CO_2 uptake during the day (negative NEE values) starting immediately after seed germination (around 20th November 2006).

f) We used both the Wheldrake forest soil respiration and the York NEE perspex flux data for modelling with SPA/DALEC by 4 jointly supervised mathematics project students in collaboration with CTCD-Edinburgh (Figure 18-8 (L)). Both projects revealed important model improvement needs, such as including an autotrophic soil respiration component and a different temperature sensitivity of individual soil respiration components (Figure 18-8 (R)).



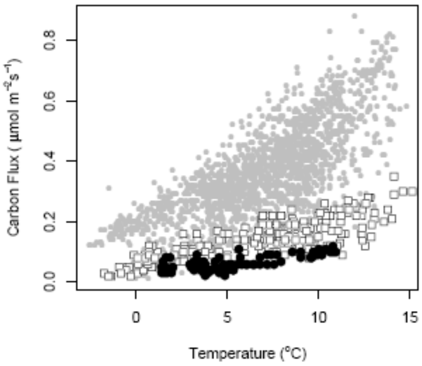


Figure 18-8: (Left) Measured (dots) vs. modelled (line) NEE fluxes from the clear NEE perspex chambers during November 06 – January 07 in the NEE flux experiment, showing net uptake (negative) during the day after germination (i.e. day 20) and net release/respiration (positive) during the night. (Right) Interestingly, we got an insight into the temperature sensitivity of different soil respiration components: soil only, root and shoot + root, from pre-seed soil only (black dots), germination (white squares) and plant growth periods (grey dots), respectively; they respond differently to temperature. Overall the model underestimates negative NEE fluxes.

g) A further crucial development was the acquisition and testing of the (INNOVA) CH_4 and N_2O analyser, coupled to the multiplexed Li-Cor soil respiration chambers. This enables fast trace gas flux measurements in the lab. In fact, we have also tested it in the field on the back of an all terrain vehicle, making it suitable for proposed phase 2 catchment scale studies. We have already used this joint system (INNOVA – Li-Cor) within a collaborative UK peatland flux project at Leeds Geography Dept., testing water-table changes on six contrasting (N and S levels) UK peatland soils (Figure 18-9). This work is currently being written for submission to J. of Hydrology.

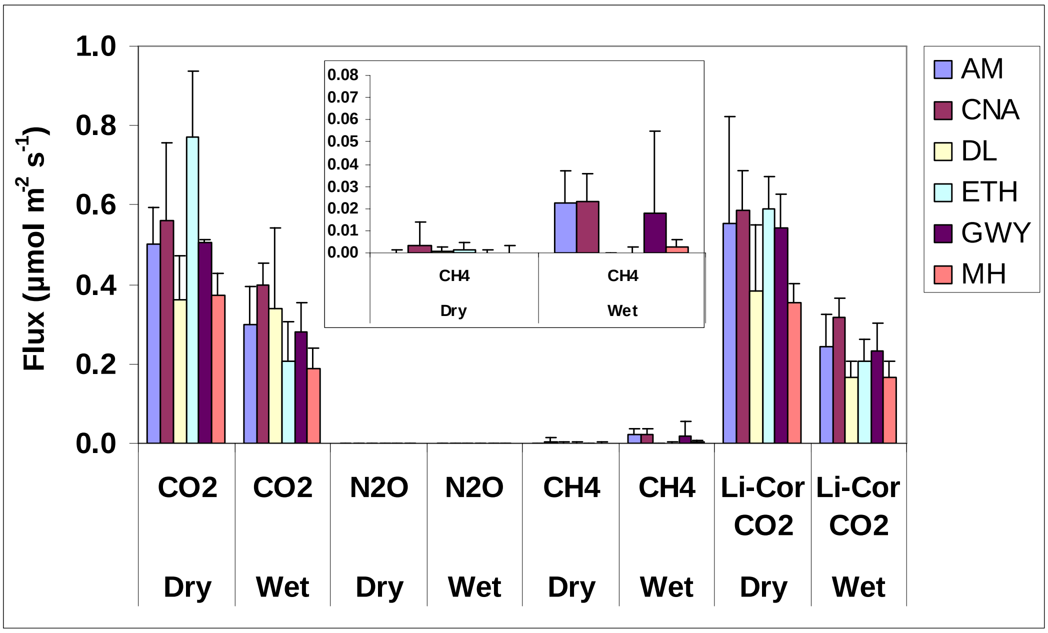


Figure 18-9: The first experimental data from the joint INNOVA and Li-Cor flux system collected during the Leeds peat water-table change study (wet: water table at surface vs. dry: at bottom of soil core) using peat from 6 UK sites; shown are the overall CO_2, CH_4 and N_2O fluxes (from the INNOVA) and also for comparison the Li-Cor CO_2 fluxes per site and treatment after 6 weeks of treatment. Note the relatively high CO_2 fluxes in the dry cores compared to the wet collars, the latter producing higher methane fluxes (also see inset) but only at some sites.

h) All the above findings are linked to the ongoing process of updating the conceptually new soil carbon sub-model for SDGVM. We are aiming to test the model this year with the high quality field data acquired from our contrasting mineral vs. organic soil sites (i.e. Wheldrake Forest and Moor House). Further ongoing work is the continuation of our advisory role within CTCD on EO related soil moisture work and an improved UK uncertainty analysis data based on a recent publication (Kennedy *et al.* in press).

18.3.2 Vulnerability of organic matter to decomposition caused by warming

The organic matter of soils is a large storage term in the carbon cycle and its breakdown could be a positive feedback in the climate system. In NW Europe we have a high component of organic matter because of the prevalence of peaty soils. Models of the carbon cycle have a simple parameterisation of the carbon cycle, possibly much too simple. Here, we carry out experimental observations on the decomposition of organic matter under a range of temperatures. Measurements have been made of the CO_2 efflux from soil material taken near the surface (5-15 cm deep) and at depth (25-35 cm) at Harwood Forest in Northumberland. The soils were removed to the laboratory and CO_2 efflux (‘soil respiration’) was measured at a range of temperatures using a Tunable Diode Laser (TDL) to examine the isotopic signal of the respired carbon, as well as to measure the overall flux. The surface samples showed respiration rates that were about four times higher than the deeper samples. The analysis of the temperature sensitivity of these data yielded Q_{10} values in the range 2.3 to 4.0, and it showed that the temperature sensitivity is greater in the surface layers than at depth. Moreover, in long term incubations, the soil respiration declined;

we think we are seeing a depletion in the supply of organic substrate from the plants. We conclude that simple Q_{10} models of soil respiration, as used in most mathematical descriptions of the carbon cycle, may not be adequate. We further investigated the response to temperature by investigating the separate efflux of $^{12}CO_2$ and $^{13}CO_2$.

It is hypothesised that this will give clues about the nature of the respiratory substrate; for example, fractions derived from woody material are rich in lignin and it is known that the carbon in lignin is more depleted than that in cellulose. The experiment clearly demonstrated the capacity of the TDL to measure the separate fluxes with good precision at the higher temperatures; however, the differences in the isotopic ratio between surface and deep soil samples were only small. It remains to check the isotopic signature of the substrates themselves, but the tentative conclusion is that most of the respired CO_2 from the deep soil is derived from non-lignin materials; it may be that the lignaceous compounds are stored in a relatively permanent way and are not vulnerable to decomposition. In April 2007 the TDL was installed in the mobile laboratory and driven to Les Landes forest in SW France, where field measurements of isotopic fluxes will be made in a contrasting type of forest in collaboration with a French group from INRA.

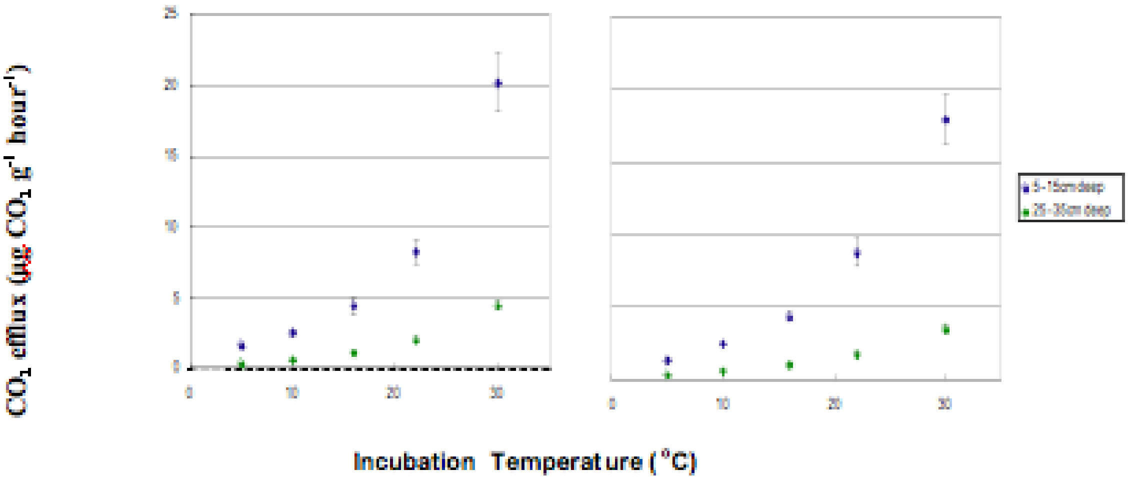


Figure 18-10: Effect of temperature on the CO_2 efflux from soils tested immediately (short term, left panel) and soils incubated for six weeks (longer term, right panel). Blue points denote surface soil samples, green denotes deep soil samples; bars represent the 95% confidence interval.

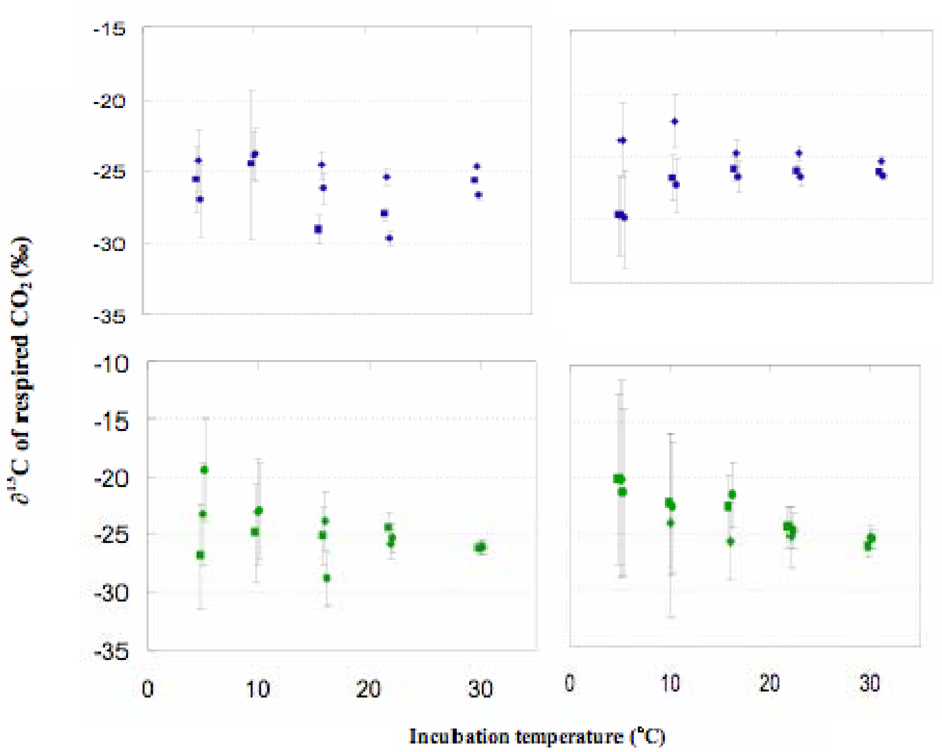


Figure 18-11: Isotopic ratio of the respired CO_2 at a range of temperatures. Symbols are as for Figure 18-10. It is notable that very precise isotopic ratios are obtained only when temperatures exceed 20 ºC.

18.4 Data assimilation and C modelling

18.4.1 DALEC development and testing

Uncertainties in coupled climate-carbon cycles models remain great as revealed by the large differences in performance in a recent model inter-comparison. This uncertainty is due in part to poorly constrained parameters, inadequate representation of ecosystem processes and a lack of strong data constraints. A key area of ongoing research within CTCD is how a wide range of available data combined with newly emerging data assimilation (DA) techniques can be utilised with C cycle models to better quantify and reduce model uncertainty. The work of Williams *et al.* (2005), who introduced a simple C cycle model (DALEC) created specifically for DA, has been further developed to ensure that it has sufficient complexity to adequately represent critical biospheric processes and then tested at a number of Fluxnet network eddy covariance measurement sites. One key advance has been in the development of a phenology module. DALEC was initially developed for use in an evergreen, needle-leaf ecosystem but to be widely applicable the model needs to be able to simulate deciduous canopies. Additionally, high level EO products (i.e. MODIS LAI) potentially provide a rich data source about phenology at a global scale, constraining GPP estimates when assimilated into the model. Adding a phenology module required a number of model modifications, including incorporating an additional, labile carbon pool and parameters to control the timing of leaf out, leaf fall and maximum foliar carbon values. Extensive testing at deciduous Fluxnet network sites in North America and Europe using ground-based and MODIS LAI estimates has produced a phenology module which uses a growing degree day scheme to successfully simulate annual variations in leaf area which strongly constrains productivity that is evaluated again flux tower NEE observations.

A main aim of DALEC is to produce a model which can be used for spatial assimilation, fully utilizing the global extent of many EO products. This will necessitate that model parameters and initial conditions, along with their associated uncertainties, be extrapolated away from the intensively studied Fluxnet sites at which they have been tested. The CTCD-led Regional Flux Extrapolation Experiment (REFLEX) is an international intercomparison of model-data fusion (MDF) techniques in C cycle models to be launched in May 2007. This has the aims of (1) comparing the strengths and weaknesses of various MDF techniques for estimating carbon model parameters and predicting carbon fluxes and (2) quantifying errors and biases introduced when extrapolating fluxes in both space and time. A full suite of ground-based and EO data from the first of 'paired' within-biome Fluxnet sites is being used to 'train' the DALEC model using a variety of MDF techniques and then model performance will be tested at a second site where only more limited (principally EO) data will be available to participants. Initial results from this experiment are expected in autumn 2007.

18.4.2 Model parameter estimation from atmospheric CO_2 measurements

Quantifying landscape C dynamics has largely been undertaken using either top-down (spatially averaged) and bottom-up (site/species specific) approaches. Top-down approaches might involve inverting global CO_2 flask measurements, whereas bottom-up methods might involved linking a series of eddy flux tower measurements. The spatial heterogeneity of C, water and energy fluxes causes difficulties when attempting to relate these different approaches to one another. The planetary boundary layer (PBL) provides a potential stepping stone between the two approaches. The PBL is in direct contact with the land surface, and dynamics within this atmospheric region are driven by ecosystem processes. Models of the PBL and biosphere provide a link between the top-down atmospheric and bottom-up ecosystem measurements by simulating processes independent of scale. The same models can be used to invert PBL observations to provide information about land surface parameters.

The Monte Carlo inversion method is just one form of analysis resulting from Bayes' theorem. Bayes' theorem allows previously held knowledge about a system (priors) to be revised using new observations. We used a simple Monte Carlo inversion scheme and a coupled atmosphere-biosphere model to investigate the interactions of the atmospheric (spatially averaged) and biosphere (site-specific) systems. A Bayesian inversion was performed using twin-data (i.e. a synthetic system for proof of concept), flat priors and a coupled PBL-biosphere model. The posterior distributions obtained for this inversion shows that information about land surface parameters can be inferred from PBL and/or eddy covariance data. However, the data resolution was not equal for all parameters and observations contain less information about foliar nitrogen, plant hydraulic conductance and albedo, and no information on the surface roughness. Combining eddy covariance and PBL observations is shown to be potentially very powerful; inverting both atmospheric and eddy covariance data improves the performance of the inversions by reducing the average uncertainty on the posterior distributions by 84% (compared to eddy covariance data only) and 74% (compared to atmospheric profile data only). In general terms, this result also shows that there is potential to make inference about the land surface from observations in the PBL alone.

18.4.3 Assimilation of EO data

Assimilation of EO data into ecosystem models provides a mechanism to constrain predictions of carbon flux away from the data-rich environments used to test and parameterise the models. The spatially synoptic nature of medium resolution EO data (MODIS, AVHRR, VGT, etc) makes it the only viable observation of global dynamics at sub-seasonal time scales for data assimilation. An attractive option for assimilating EO data into ecosystem models is to use "high-level" products such as leaf area index or GPP. Such products are linearly related to the model state vector and the construction of an observation operator is thus trivial. Two key arguments against the use of such products are: a) their error characteristics (critical for DA) are often only poorly known and, b) assumptions used in their derivation may contradict those of the ecosystem model itself. Both of these points may be addressed by using "low-level" EO products such as reflectance data. Whilst these data are still products per se, assumptions made in their derivation are independent of those made in the ecosystem model. The construction of an observation operator to assimilate such data is non-trivial however. We have replaced our previous reflectance observation operator with a hybrid geometric-optic radiative transfer model (GORT) based on the work of Ni *et al* (1999). This is more suitable for forest canopies consisting of discrete, individual crowns than the previous operator and we have demonstrated its ability to model and assimilate MODIS reflectances for a site on the Oregon transect. This work has been accepted for publication in the forthcoming special issue of Remote Sensing of Environment on Data Assimilation (Quaife *et al.* 2007). Assimilating MODIS reflectance data was shown to considerably improve the modelled NEP estimates when compared to the model running with no assimilation (Figure 18-12).

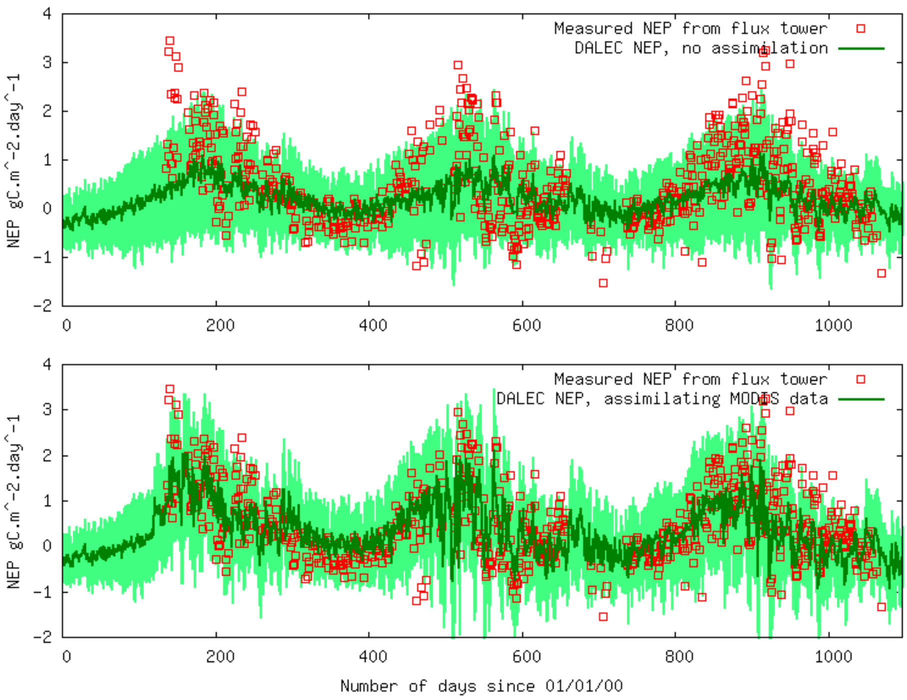


Figure 18-12: Measured and predicted net ecosystem production (NEP, positive represents a net sink) for a young ponderosa pine stand in central Oregon. Measured NEP is derived from a flux tower (data are shown in both panels). Top panel predicts NEP using an ensemble simulation of the DALEC model with an optimised parameterisation and a model error term. The lower panel uses the EnKF to assimilate MODIS reflectance data to update the model ensemble. Green bars show one standard deviation around the mean of the ensemble. Assimilation clearly reduces model bias.

18.5 References

Briones, M.J.I., Ineson, P., Heinemeyer, A. Predicting potential impacts of climate change on the geographical distribution of enchytraeids: a meta-analysis approach. *Global Change Biology*, (accepted).

Hartley I.P., Armstrong A.F., Murthyw R., Barron-Gafford G., Ineson P. and Atkin O.K. (2006) The dependence of respiration on photosynthetic substrate supply and temperature: integrating leaf, soil and ecosystem measurements. Global Change Biology **12** 1954-1968.

Hartley, I.P., Heinemeyer, A., and Ineson. P. (in press a) Effects of three years of soil warming and shading on the rate of soil respiration: substrate availability and not thermal acclimation mediates observed response. *Global Change Biology*.

Hartley, I.P., Heinemeyer, A., Evans, S.P., and Ineson. P. (in press b). The effect of soil warming on bulk soil versus rhizosphere respiration. *Global Change Biology*.

Heinemeyer, A., Ineson, P., Ostle, N. and Fitter A.H. (2006). Respiration of the external mycelium in the arbuscular mycorrhizal symbiosis shows strong dependence on recent photosynthates and acclimation to temperature. *New Phytologist* **171**: 159-170.

Heinemeyer, A., Hartley, I.P., Evans, S.P., Carreira de la Fuente, J.A. and Ineson, P. (in press). Forest soil CO_2 flux: uncovering the contribution and environmental responses of ectomycorrhizas. *Global Change Biology*.

Kennedy, M.C., Anderson, C.W., Heinemeyer, A., Lomas, M.R., O'Hagan, A., Quegan, S., and Woodward, F.I. (in press). Quantifying Uncertainty in the Biospheric Carbon Flux for England and Wales. *Journal Royal Statistical Society*.

Ni, W.G., Li, X.W., Woodcock, C.E., Caetano, M.R. and Strahler, A.H. (1999). An analytical hybrid GORT model for bidirectional reflectance over discontinuous plant canopies. *IEEE Transactions on Geoscience and Remote Sensing*. **37** (2): 987-999.

Quaife, T., Lewis, P., De Kauwe, M., Williams, M., Law, B.E., Disney, M. and Bowyer, P. (2007), in press. Assimilating Canopy Reflectance data into an Ecosystem Model with an Ensemble Kalman Filter. *Remote Sensing of Environment*.

Williams, M., P.A. Schwarz, B.E. Law, J. Irvine & M. Kurpius (2005). An improved analysis of forest carbon dynamics using data assimilation. *Global Change Biology* **11**, 89-105.

19. Soil carbon and peat extraction in Northern Ireland (WP 2.16)

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19.1 Soil Carbon survey on 5 km grid for Northern Ireland – identification of changes in soil C since last survey

The first systematic survey of the soils of Northern Ireland was carried out during the period 1988-97 and involved the mapping and classification of soils at a scale of 1:50,000. As part of this survey, on predominantly agricultural soils, sites were sampled down to parent material, by horizon, from survey pits located on a near regular 5km grid. In winter 2004-05 (Dec'04-Feb'05), the soils of Northern Ireland were re-sampled on the same 5km grid but extended to include soils from all regions of the Province viz. agricultural, semi-natural, upland and urban. Two sample depths were used in the re-survey viz. 75mm (for agronomic purposes) and to the A-horizon (for comparison with the previous survey). Sample locations were identified using GPS. In all, 582 soils were sampled in 2004-05 (an additional 103 samples compared with the 1988-97 survey) and subjected to physical and chemical analysis including total Carbon (%C). The complete dataset of %C results for the re-survey became available in February 2007.

A statistical summary of the results is given in Table 19-1 (for all records) by land use class. The distribution of soil-C across Northern Ireland is shown in Figure 19-1 using graduated dots to represent %C concentrations in classes <5, 5-10, 10-20, 20-40 and >40%C.

Table 19-1: Average soil % carbon values (with standard deviations in brackets) by land use class for all 582 soils sampled across Northern Ireland on a 5km grid during Winter 2004-05.

Land Use	No. of records	%C (top 75mm)	%C (A-horizon)
Arable	24	4.18 (2.36)	3.90 (1.75)
Conifer Forest	27	44.82 (14.11)	44.79 (15.94)
Deciduous Forest	5	9.67 (5.23)	10.57 (7.62)
Extensive Grazing	59	45.91 (12.37)	46.61 (14.32)
Grazing	367	8.38 (5.51)	7.03 (5.45)
Silage	35	6.23 (2.29)	5.15 (1.85)
Rough Grazing	28	15.86 (8.88)	15.36 (10.09)
Semi-natural	10	44.54 (11.91)	43.87 (15.71)
Urban Amenity	8	5.94 (3.37)	5.09 (3.28)
Others (mixed use)	19	12.54 (12.85)	11.19 (13.73)

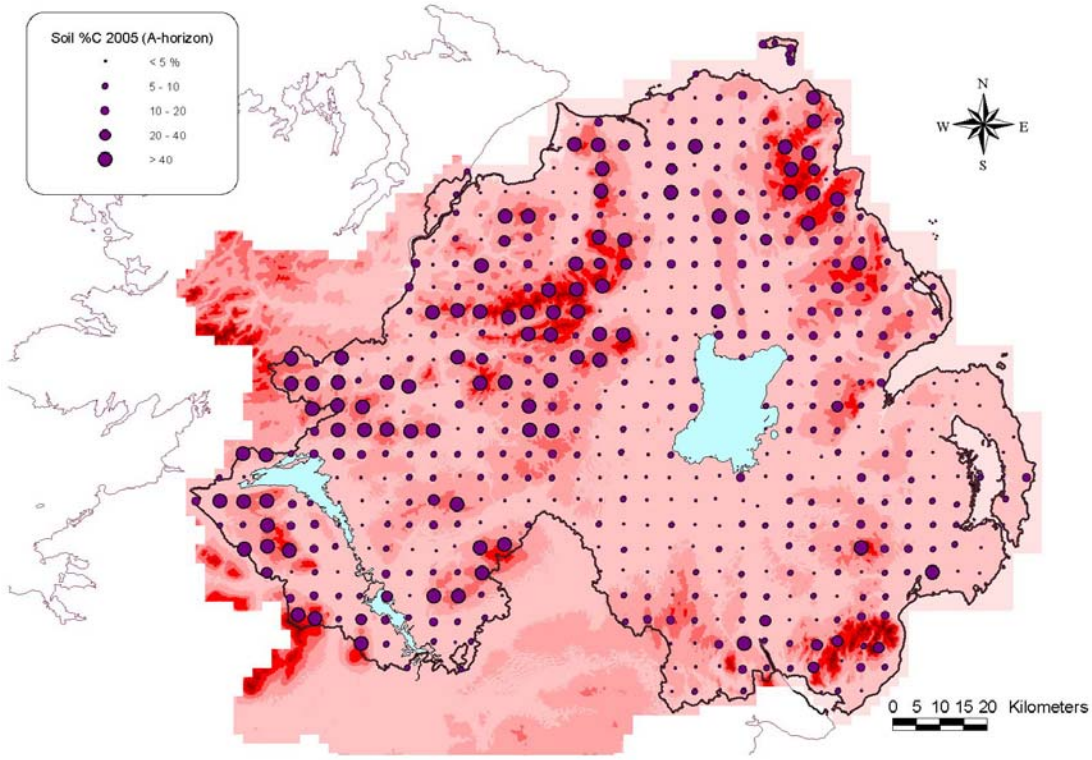

Figure 19-1: The distribution of soil C concentrations (%) on a near regular 5km grid for soils sampled in winter 2004-05 (A-horizon), superimposed on a digital elevation model for Northern Ireland (higher altitude = darker pink/red).

In order to estimate the degree of change in soil C concentrations between the two surveys, the datasets (possible for A-horizon samples only) from the 2 periods were matched using a Geographic Information System (viz. ESRI's ArcGIS). Exact matches could not be made because of the different systems used to identify the coordinates of the sample points (approximate map references used in 1988-97 vs. GPS readout for 2004-05) but it was possible to match sample points in close proximity (median positional difference 123m, with 95% of samples within 500m of each another). For brevity, from here on, the 1988-97 survey will be referred to as the '1995 survey'.

A statistical comparison of the matched records from the 2005 vs. 1995 datasets is summarised in Table 19-2 and the % change in the mean %C value from 1995 evaluated for each of the 5 main land uses represented in the matched dataset. Also included in Table 19-2 are the linear regression parameters for the lines of best fit for %C 2005 (y-axis) vs %C 1995 (x-axis) for each class together with their respective regression coefficient (as R^2).

Table 19-2: A statistical comparison of the matched 2005 vs. 1995 soil carbon dataset summarised by land use together with the regression lines for %C 2005 (y-axis) vs. %C 1995 (x-axis) by land use.

	%C 2005	%C 1995	%C 2005	%C 1995	%C 2005	%C 1995	%C 2005	%C 1995	%C 2005	%C 1995
	Arable		**Coniferous Forest**		**Extensive/Semi-natural**		**Managed Grassland**		**Rough Grazing**	
Count	17	17	16	16	51	51	318	318	19	19
Minimum	1.33	1.62	10.40	7.29	4.24	3.51	1.96	0.77	4.07	3.96
Mean	3.73	3.85	47.01	39.39	46.03	35.64	6.80	6.21	15.77	13.14
Median	3.38	3.54	53.55	42.80	52.70	45.40	5.64	4.67	12.90	8.57
Maximum	7.68	7.67	54.60	51.80	56.50	52.50	51.10	49.80	35.80	51.30
1st Quartile	2.06	2.46	50.10	37.05	50.75	19.80	4.14	3.73	8.62	5.76
3rd Quartile	4.82	4.84	53.78	46.03	53.80	48.17	7.81	6.42	21.00	15.65
Interquartile Range	2.76	2.38	3.68	8.98	3.05	28.37	3.68	2.69	12.38	9.89
%change vs. 1995	**96.8**		**119.4**		**129.2**		**109.6**		**120.0**	
Regression line (thro' origin)[a]:										
							%C2005>=%C1995	**%C2005<%C1995**		
No of matched records	17		16				105[a] (from 221)	61[a] (from 97)		
slope	**0.965**		**1.183**				**1.123**	**0.862**		
R^2	0.853		0.881		ns[b]		0.969	0.951	ns[b]	

[a] For the managed grassland classes, the soil dataset was split in two, one part for those records where %C2005>=%C1995 and a second set where %C2005<%C1995. In order to see the underlying trend, poorly matched points ('outliers') were identified and removed from the comparison for the grassland subsets if the soil %C in 2005 was 30% higher, or 30% lower, than the matched soil %C value for 1995 (i.e. 0.7 * %C1995 > %C2005 >1.3 * %C1995).

[b] ns = not significant.

In conclusion:

- Most (about two-thirds of) grassland soils in Northern Ireland have been slowly accumulating C at an annual average rate of about 1% of their original value.
- Arable and some managed grassland soils (those with a change in land use since 1995 or having had a recent reseed), in Northern Ireland have been losing C at an average annual rate of about 0.4% and 1.4%, respectively.

These conclusions have important implications for the updating of the soil C inventory values for Northern Ireland. Bulk density measurements (taken from top 50mm; volume $222cm^3$) for each sample from the 2004-05 survey are nearing completion and should help improve the accuracy of the carbon load estimate in the topsoils of Northern Ireland.

19.2 Carbon losses due to Peat Extraction in Northern Ireland

19.2.1 Peat Extraction for Fuel

A sampling network for fuel peat extraction has been derived. Initially a 5% random sample of 1km x 1km grid squares from the Northern Ireland Peatland Database (Cruickshank *et al*., 1993) gave 102 grid squares with lowland peat and 154 squares of blanket peat. Of these squares 19 lowland and 29 blanket had fuel extraction in 1991, which represent around 4% of the incidences of extraction in 1991. Drawing the sample from all grid squares with peat led to the inclusion of the fens of Cos. Down and East Armagh in the lowland sample, and of the Mournes – Slieve Croob and Slieve Gullion in the blanket sample. These are areas in which machine cutting was not found in 1991, nor likely to be found because (a) the fens have no suitable peat left in them (they are fens because centuries of hand cutting has removed the acid peat) and (b) these upland peats are thin and on relatively steep slopes. A 5% random sample excluding these areas gave 85 grid squares with lowland peat and 25 incidences of machine fuel cutting (approx. 6% of incidences). For blanket peat the sample gave 121 grid squares and 52 incidences (approx. 5% of incidences).

The contract for the work came late in the summer (July 2006) so that by the time field survey could begin the cutting season had largely been missed; it was not possible to achieve the first one-third of field sampling. Instead, work on horticultural extraction was moved forward (see below).

Complementary evidence of trends in fuel peat extraction

Forest Service (NI) lets turf banks annually. Up to 1987 the number of people to whom turf banks were let is reported in the Forest Service Annual Report; thereafter, with the exception of two years for which there are no data, Forest Service records the number of turf banks let. It is assumed that in the years to 1987 most people would lease only 1 bank. If that is the case, then the ‘turf banks let’ is at a maximum in 1983, falling rapidly thereafter (Figure 19-2) to less than 4% of the maximum in recent years. The data do not distinguish between hand cutting and machine cutting, but it is notable that machine cutting was introduced into Northern Ireland in 1981. Wet summers reduced harvesting in 1986 and the impact of the oil crises, that in part had stimulated peat cutting in the 1980s, began to lessen in the 1990s. Additionally, national campaigns to reduce peat extraction may have had an effect. It may be that availability of Forest Service turf banks also declined. However, whilst the area of unplantable land in turbary and in turbary rights has declined (Figure 19-2), it has remained fairly constant in recent years (although some data is awaited from Forest Service (NI)) while the lettings have continued to decline steeply. Looking at the number of turf banks per hectare of turbary, this declines from 0.87/ha in 1983 to 0.1/ha in 2002 (the last date for which data are currently available) - this suggests that the decline in the number of turf banks let is the result of a decline in demand rather than availability.

Comparison of Forest Service lettings in 1991 with the number of incidences found across Northern Ireland (Cruickshank *et al*., 1995) indicates that the Forest Service lettings may have accounted for around 50% of incidences. If that were to be the percentage at present, there could be as few as 150 fuel extraction sites today. However, that assumes that decline in the number of extraction sites has been the same outside Forest Service land as within. Nevertheless, the trends in Forest Service lettings lend support to impressions gained from field observation and discussions with foresters and conservation personnel that fuel extraction has declined - but data on the extent of the decline will come from the field survey.

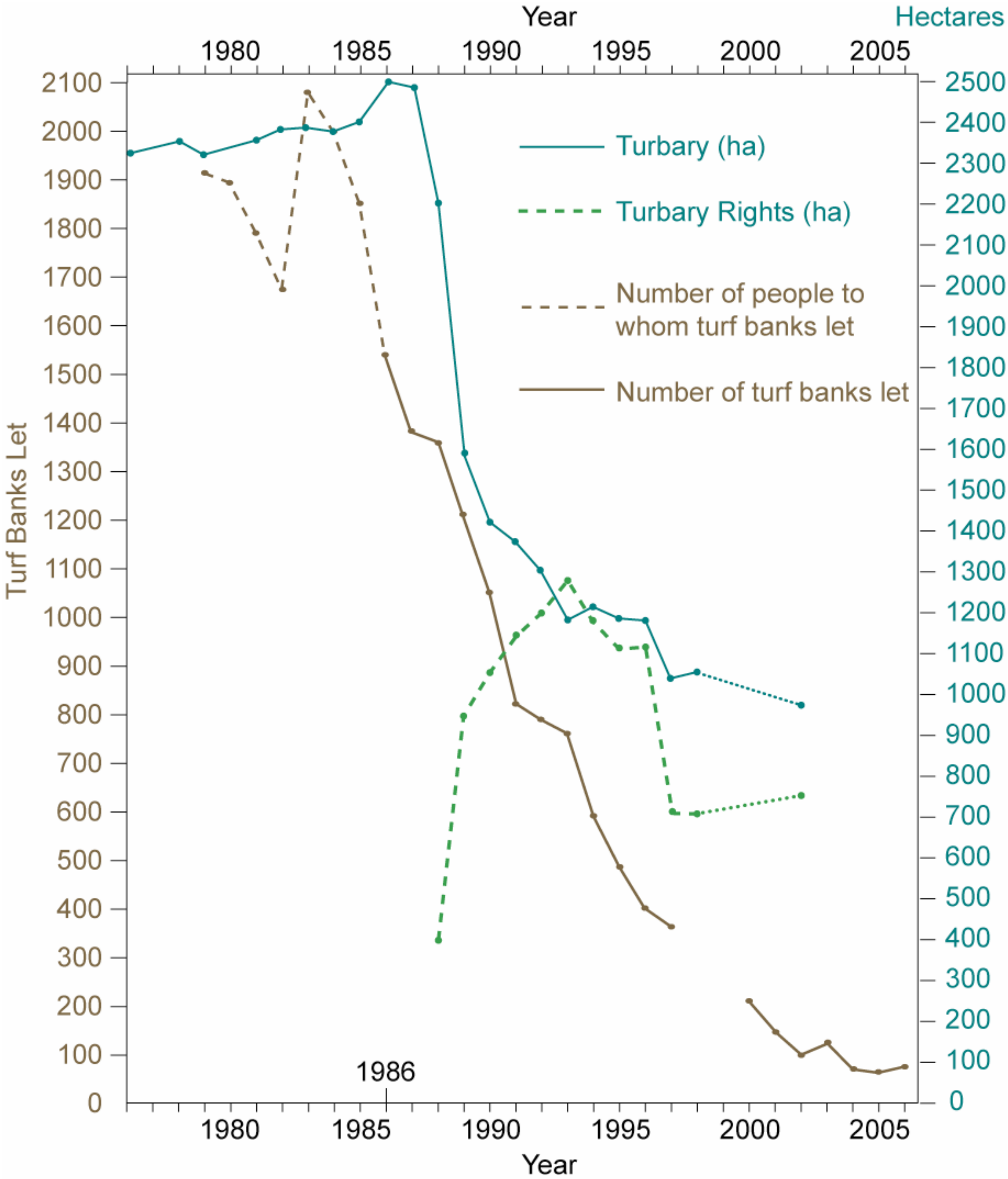

Figure 19-2: Area of turbary, turbary rights and number of lettings for turbary on Forest Service land. (Source: Data from Forest Service (NI) Annual Reports and unpublished data from Forest Service (NI))

19.2.2 Peat Extraction for Horticulture

The first stage was to review previous estimates of carbon loss in the early 1990s. In the 1996 Report (Cruickshank *et al*., 1996) the estimate was based on volumes of peat extracted using information from planning applications. Subsequently, it proved difficult to obtain similar data; also, because the estimated carbon losses were derived from forecast volumes given in the planning applications they did not necessarily reflect the subsequent productive areas. Using our existing database of peat extraction (identified from satellite images and field visits) which gave areas for each site, and assuming an annual removal of 10cm of peat (from discussion with producers and review of estimated extraction rates in the Republic of Ireland) and a C content of 5.08 kg/100 litres (constant from the 1996 report), the estimated C extraction in 1991 was 38,456 tonnes C. This compares with 31,902 tonnes estimated in the 1996 Report. Note that 10cm of annual removal is a conservative estimate relating to a long-term average that considers variations in seasonal conditions.

Satellite imagery for 2001 has been examined and sites of horticultural extraction identified and measured. (But checking all sites to ensure they were horticulture extraction is not complete). Using the same procedures as for 1991, this has produced an interim C extraction of 37,389 tonnes. The procedures will be repeated for the latest imagery available close to the end of the contract.

It appears that C losses from horticultural peat extraction in 2001 were similar to those in 1991. Bearing in mind changes in methodology (including advances in image interpretation and measurement of sites), and that some sites remain to be confirmed (including changes in type of extraction), C losses from horticultural peat extraction in 2001 are not too dissimilar from those reported in 1996.

19.3 References

Cruickshank, M M, Tomlinson, R W, Dunwoody, C, Bond, D, and Devine P M (1993) A peatland database for Northern Ireland: methodology and potential resource. *Biology and Environment: Proceedings of the Royal Irish Academy* **93B** 1. 13-24

Cruickshank, M M, Tomlinson, R W, Bond, D, Devine, PM and Edwards, C J W (1995). Peat extraction, conservation and the rural economy in Northern Ireland. *Applied Geography*, **15**, 365-83.

Cruickshank, M M, Tomlinson, R W, Devine, P M and Milne. R. Carbon pools and fluxes in Northern Ireland. Section 4 Carbon sequestration in vegetation and soils. Report March 1996 to Global Atmosphere Division, Department of the Environment.

20. Quantification of uncertainties in the inventory (WP 3)

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20.1 Introduction

WP3 aims to comprehensively quantify the uncertainties in the inventory. This includes quantifying uncertainties in empirical information and uncertainties associated with calculations and process-based modelling. The ultimate aim is to provide a rigorously determined measure of reliability to all parts of the inventory produced in WP1. Uncertainty quantification (UQ) in the inventory project is complicated because different parts of the inventory are calculated in different ways, depending on the output variable of interest. Figure 20-1 shows schematically the flows of information in the project.

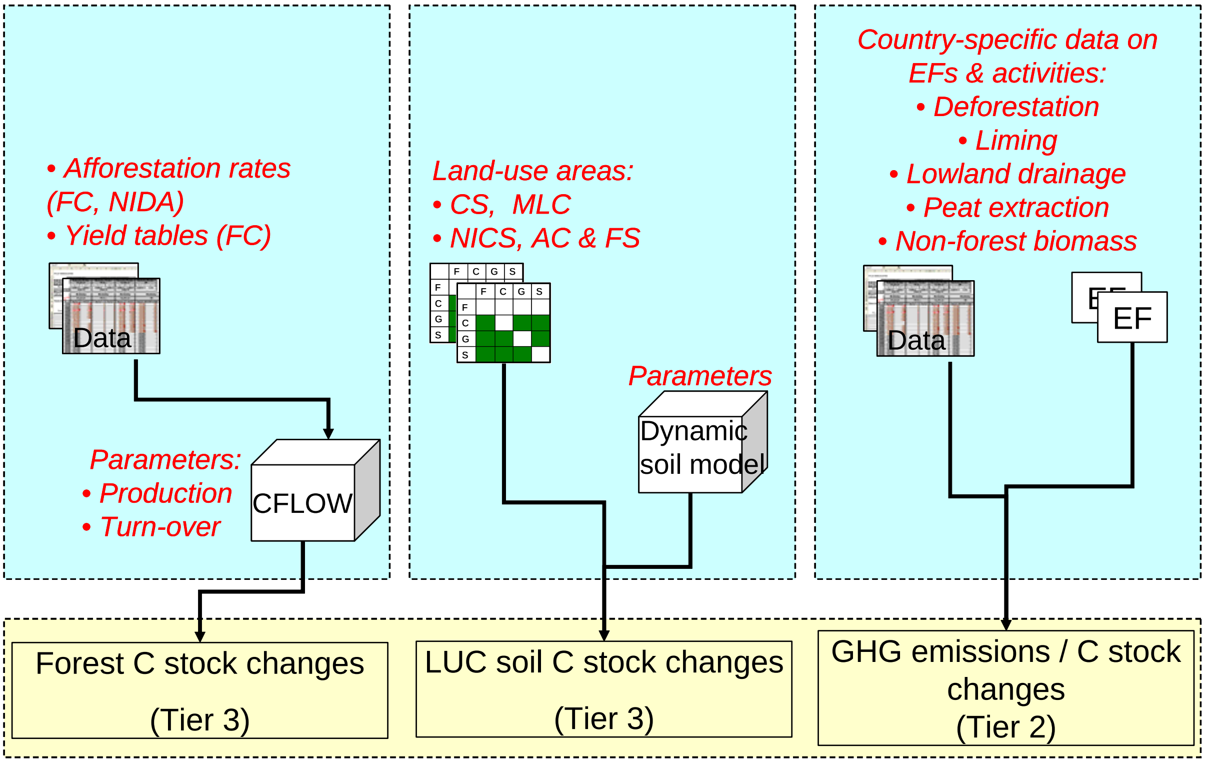


Figure 20-1: Information flows in the calculation of the UK GHG Inventory associated with LULUCF. In red italics: input factors. In yellow boxes: the three major types of output.

As the Figure shows, there are three major flows of information. First, changes in forest carbon stocks are calculated for areas afforested after 1920, using data provided by the Forestry Commission and NIDA, followed by data-processing using the CFLOW model. The second flow of information is to calculate soil carbon stock changes associated with land use change, using land-use change matrices derived from various sources (see Figure), followed by data-processing by means of simple dynamic soil models that quantify the progression over time from one soil-C equilibrium towards another. The third flow of information uses the IPCC Tier 2 activity data and emission factor approach to calculate GHG emissions and C stock changes associated with a range of specific activities including deforestation, liming, lowland drainage and peat extraction. Associated with all three flows of information are uncertainties, first of all in the numerous input factors used in the calculations (indicated in red italics in the Figure), but also in the choice of calculation tools (the CFLOW model, soil models, Tier 2 emission calculations). It is the task of WP3 to quantify these uncertainties and determine how they propagate to the output variables indicated at the bottom of the Figure.

Note that the scheme only shows the information flows for the methods currently applied in the inventory. As described in various work packages in group 2, we are working towards the use of extra information (regional differences in climate, soil nitrogen content etc.) and more tools (in particular more detailed process-based ecosystem models) in the inventory. This will inevitably lead to more demands on UQ.

UQ was already applied in previous instalments of the inventory. However, this was restricted to preliminary simulations of carbon sequestration in forests by means of the model BASFOR, and estimation of land-use changes between non-forest land use categories, where sensitivity of calculated stock changes to input uncertainty was examined by means of Monte Carlo simulations. Both of these activities are carried out more rigorously in the current project (WP's 2.11 and 2.13) and WP3 builds on their results.

In the following two sections of this annual progress report, we describe the methodology and the progress to date.

20.2 Methodology

The basis of our method for UQ is IPCC Good Practice Guidance methodological Tier 2. We first quantify the uncertainties associated with the many input factors used in the inventory calculation, by expressing them as probability distribution functions (pdf's). Then representative samples are taken from the pdf's to propagate input uncertainty forward through the calculations. This results in representative samples of the desired output variables. Although this method is relatively straightforward, it needs to be applied with caution. If the only source of information for the input factor pdf's is direct measurement or expert opinion, the resulting output uncertainty may be overly high, because knowledge about inputs is generally incomplete, input factors interact and uncertainty may propagate nonlinearly in the calculations. To prevent generating inventory uncertainty estimates that are unrealistically high, or even unusable in practice, we need to reduce input uncertainties where possible, but we also need to combine direct and indirect information when estimating uncertainties. We apply Bayesian techniques to incorporate as much information in our pdf's as possible (Patenaude *et al*., 2005). The techniques make extensive use of Bayes' Theorem:

$$p(\theta|D) = c\ p(D|\theta)\ p(\theta)$$

where $p(\theta|D)$ is the so-called posterior pdf for our input factors θ after incorporating new direct or indirect information D, $p(\theta)$ is the prior pdf for θ that we had before arrival of the new information D, $p(D|\theta)$ is the likelihood of D for given values of θ, and c is a proportionality constant. Bayes' Theorem is valuable for the inventory because it is often relatively easy to quantify the likelihood of new information in which case the theorem tells us immediately how our uncertainty about the input factors θ decreases because of that information. Useful information D could be measurements of carbon stock changes or emissions, i.e. the key output variables of interest in the inventory, but equally well measurements of any other variables that play a role in the inventory calculation such as litter fall rates or SOM-decomposition rates that are intermediate variables in the calculations of the CFLOW model.

Bayes' Theorem is valid without limitation and we shall apply it to all three flows of information in the inventory. This includes the calculations of both past GHG and C-stock dynamics as well as the projections of future CO_2 emissions and removals in WP 1.4. Obviously no measurements of future emissions are available to feed into Bayes' Theorem, but the parameter uncertainty of the models used for future projections can be reduced by

Bayesian calibration using existing data. The long-term perspective of the approach is that the annual generation of the GHG inventory becomes a self-learning system where new information, even including observed mismatches between past projections and current observations, automatically leads to improvement of the calculations.

20.3 Progress to date

The focus of the work in WP3, in the current reporting period, has been on putting the methodology in place. This included comparing the approach extensively with methods proposed by other parties and collecting preliminary information on uncertainty in input factors.

20.3.1 Review of existing guidelines for uncertainty quantification

A comprehensive literature review was carried out to assess how various international organisations related to the environmental and natural sciences have drafted guidelines, protocols or standards for UQ. Table 20-1 lists those that were found to be relevant to the inventory work.

Table 20-1: Internationally used guidelines, protocols and standards relevant to uncertainty quantification in the UK GHG Inventory associated with LULUCF.

Guidelines, protocols, standards	***Long name***	***Organisation***	***Year***	***URL***
ISO-14064		ISO	2006	www.ecologia.org/ems/ghg
GHG-Protocol	Greenhouse Gas Protocol Initiative	WBCSD/ WRI	2004-2005	www.ghgprotocol.org
2006 IPCC Guidelines	2006 IPCC Guidelines for National Greenhouse Gas Inventories	IPCC		www.ipcc-nggip.iges.or.jp/public/2006gl
GPG-LULUCF	Good Practice Guidance for Land Use, Land-Use Change and Forestry	IPCC	2003	www.ipcc-nggip.iges.or.jp/public/gpglulucf
GPG2000	Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories	IPCC	2000	www.ipcc-nggip.iges.or.jp/public/gp
GMP-Handbook	Good Modelling Practice Handbook	STOWA *et al*	1999	www.estuary-guide.net/pdfs/STOWA-RIZA%20guide.pdf
NIST-TN1297	Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results. NIST Technical Note 1297. 1994 Edition.	NIST	1994	physics.nist.gov/Document/tn1297.pdf physics.nist.gov/cuu/Uncertainty
AEAT-2688	Treatment of Uncertainties for National Estimates of Greenhouse Gas Emissions	NAEI		www.aeat.co.uk/netcen/airqual/naei/ipcc/uncertainty/contents.html
AEAT/ENV/R/1039	Estimation of Uncertainties in the National Atmospheric Emissions Inventory	NAEI	2003	www.airquality.co.uk/archive/reports/cat07/AEAT1039_finaldraft_v2.pdf
GUM	Guide to the Expression of Uncertainty in Measurement	ISO *et al*	1993, 1995	
UK-GHG-1990-1999-A8	UK Greenhouse Gas Inventory, 1990 to 1999, Appendix 8, Uncertainties	NETCEN	2001	www.aeat.co.uk/netcen/airqual/reports/ghg/ukghgi_90-99_append_7-9.pdf
Protocol-UQ/UA	Protocol for Uncertainty Quantification and Analysis	NitroEurope	2006	www.nitroeurope.eu

The published guidelines listed in Table 20-1 demonstrate the recognised importance of UQ. However, most of these guidelines only provide general advice, not going into detail except where uncertainty associated with small and random linear-scale measurement error is addressed (NIST-TN1297).

ISO-14064 provides general advice on GHG accounting and data quality assurance, but sees uncertainty primarily as something to be minimised rather than as something requiring extensive quantification or analysis: "The organization shall select and use quantification methodologies that will reasonably minimize uncertainty and yield accurate, consistent and reproducible results". It stresses that two main sources of uncertainty in GHG estimates are normally baseline uncertainty and data uncertainty. ISO-14064 recommends a very conservative quantification in case of a highly uncertain baseline. This recommendation is possibly at odds with the goal of scientific objectivity. In WP3, we aim for objective UQ. ISO-14064 is focused on use by businesses as is the document on which it is partly based, i.e. the Greenhouse Gas Protocol Initiative (GHG-Protocol), issued by WBCSD/WRI. For details of UQ, the ISO guidelines refer to the Guide to the Expression of Uncertainty in Measurement (GUM).

GUM has in practice already been superseded by the Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results (NIST-TN1297). NIST-TN1297 has a heavy focus on standardisation of how to report uncertainty, recommending the use of standard deviations in general, and the methods for UQ are mostly analytical, rather than Monte Carlo based. This does pose limitations on the applicability of their techniques.

Of central importance for the UK GHG Inventory are of course the guidelines published by the IPCC (GPG2000, GPG-LULUCF, 2006 IPCC Guidelines), NETCEN (UK-GHG-1990-1999, in particular Appendix 8) and NAEI (AEAT-2688, AEAT/ENV/R/1039). GPG2000 does not cover LULUCF but is consistent with GPG-LULUCF which does. GPG2000 stresses objectivity: inventories consistent with good practice are those that "contain neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable". Chapter 6 of GPG2000 discusses how to quantify uncertainties in practice. The central role of pdf's in UQ is emphasised, both when dealing with data and when summarising expert opinion. Both analytical (Tier 1) and numerical (Tier 2, Monte Carlo) methods for uncertainty propagation are discussed, and the use of Monte Carlo methods in estimating uncertainties by source categories is explained.

Chapter 6.5 of GPG2000 provides a very useful overview of practical considerations in the use of Monte Carlo methods. This includes advice on specifying pdf's both for data and for the prior of model parameters. It is stressed that the effort required in UQ of individual parts of the inventory should stand in proper relation to their contribution to overall uncertainty: the inventory does not have unlimited resources, so good practice entails that effort is balanced against the need for timeliness and cost effectiveness. Monte Carlo operates by sampling from the pdf's and the higher efficiency of Latin Hypercube Sampling compared to fully random sampling is explained. The chapter concludes by discussing how correlations among variables can be treated. Much of this discussion is clearly relevant to WP3.

Other information in GPG2000 useful for the work in WP3 is found in the Annexes. Annex 1 discusses the "Conceptual Basis for Uncertainty Analysis". It discusses specification of pdf's in A1.2.4-6 and suggests that good practice implies choosing full or truncated normal or lognormal distributions or – to represent absence of information – uniform or triangular distributions. This advice is debatable in the context of WP3, as the primary purpose of quantifying the pdf's is properly representing the available information about a quantity, and the best representation may be a different pdf. In preliminary work in WP3 we found beta-distributions to be appropriate in many circumstances. Moreover, when new pdf's are formed by forward propagation of input uncertainties or by applying Bayes' Theorem to calibrate model parameters, the resulting output samples need not match any of the standard distributions. Annex A1.3 provides a useful checklist of the different sources of uncertainty in GHG inventories, including those associated with measurement, sampling, lack of representativeness of data, and expert judgment. Similarly, A1.4.1 has an excellent list of 15 descriptors that – ideally – should accompany all data to allow UQ. However, experiences in projects where data providers collaborate with data users do not suggest that completion of that list will be achieved very often. A1.4.2 deals with the standard problem in any national inventory of UQ associated with sampling and upscaling in time and/or space.

Whereas GPG2000 provides valuable general methodological advice, GPG-LULUCF adds concrete advice and information for UQ in the LULUCF inventory. Chapters 2 discusses quantification of land area, land use and land use change and lists sources of uncertainty. This area will be developed further in WP 2.13 of the project which aims to develop Bayesian methods for UQ related to land-use change matrices. Chapter 3 of GPG-LULUCF provides the necessary data and methodological advice on estimating uncertainties associated with carbon stock changes and emissions estimation. Chapter 3.2.1 deals with forest land remaining forest land and gives extensive advice, including default values, on uncertainties in wood density, biomass expansion factors, root-shoot ratio, products, forest areas, SOM, litter, dead wood, soil bulk density, CO_2 and N_2O emission actors, fertilisation rates etc. However, this information is not used in the current UK inventory as we choose the option of assuming forest-remaining-forest to be carbon-neutral. In future, application of process-based forest modelling may change that approach: see the use of the forest model BASFOR in WP 2.11. Chapter 3.2.2 deals with afforestation and the role of uncertainty in changes in biomass-C-stocks, dead organic matter and litter and SOC after land-use change to forest. The key activity data here are rates of forest area increase which are found to have much lower uncertainty than the associated emission factors. The chapter tabulates a variety of sources of uncertainties in emissions and stock changes after afforestation. The remaining chapters in section 3 of GPG-LULUCF deal in a similar vein with the other considered land uses and land-use changes.

Chapter 4 of GPG-LULUCF describes supplementary methods and good practice guidance arising from the Kyoto Protocol. Overall, the uncertainty approaches are as for UNFCCC. Chapter 5 shows how to combine uncertainty estimates into overall uncertainties, reiterating much of guidance provided by GPG2000. An interesting addition, relevant to WP3, is given in Chapter 5.5.4 which deals with a specific aspect of quality control, i.e. evaluating the models that are used. The chapter recommends checking – for each model used in the inventory – the appropriateness of model assumptions, any extra- and interpolations, calibration-based modifications etc. From the perspective of WP3, we may view such model evaluation as quantifying uncertainty regarding model structure rather than input or parameter uncertainty. The Bayesian techniques used in WP3 can handle model structural uncertainty as well, but only if multiple models are available for single tasks – allowing us to define a pdf over model structures. This technique will be used for example whenever we consider replacing existing calculation methods with new ones. An example could be the replacement of Tier 2 approaches by Tier 3 ones. Finally, Chapter 5.7 of GPG-LULUCF gives a good overview of international programs and networks that are relevant to LULUCF. Obviously that list is now partly outdated and incomplete, but it still contains useful links to sources of information that can be used in UQ in WP3 (www-eosdis.ornl.gov/FLUXNET/index.html, www.bgc-jena.mpg.de/public/carboeur/, www.igbp.net/, www.gcte.org/, www.lternet.edu/, www.fao.org, www.icp-forests.org/, www.ymparisto.fi/default.asp?contentid=17110&lan=en, www.emep.int/, www.globalcarbonproject.org/, www-eosdis.ornl.gov/).

The 2006 IPCC Guidelines are consistent with GPG2000 and GPG-LULUCF, but provide an even clearer overview of issues and methods for dealing with uncertainties in GHG inventories (Vol. 1, Ch. 3). Included is a detailed example of the UQ reported for the national GHG inventory of Finland (Statistics Finland, 2005). This UQ refers to the whole inventory, not just the part associated with LULUCF, and is based on expert judgement regarding uncertainties in activity data and emission factors. Detailed examples showing how Monte Carlo methods have been used for UQ starting from pdf's for activity data and emission factors are given in UK-GHG-1990-1999-A8 (Salway *et al.* 2001, UK Greenhouse Gas Inventory, 1990 to 1999, Appendix 8) and AEAT/ENV/R/1039 (Passant 2003, Estimation of Uncertainties in the National Atmospheric Emissions Inventory).

Finally, for those parts of the inventory where dynamic modelling is used, the GMP-handbook published by STOWA and the Protocol-UQ/UA issued by NitroEurope provide advice on good practice in process-based modelling, including UQ. The latter protocol includes a brief explanation of the Bayesian approach, as advocated here in WP3, and several modelling groups in NitroEurope are now carrying out Bayesian calibration and UQ (Van Oijen *et al.*, 2006).

In summary, the documents discussed in this section give sound methodological advice that can be used in WP3, including default values for uncertainties associated with input factors used in the inventory calculations. The Bayesian methodology is covered in less detail, but as explained in section 2 of this report, it is conceptually easy and is applied in the current inventory also in WP's 2.11 and 2.13.

20.3.2 Prior estimation of uncertainties

The work in WP3 builds on input from various WP2 activities. The role of Bayesian techniques used in WP's 2.11 and 2.13 has already been mentioned. The work in 2.3, 2.12 and 2.13 helps formulating pdf's for input factors on forests and land-use change matrices, and the work in WP's 2.9-2.11, where process-based models are being developed, produce results that can be compared with the simpler calculation methods now used in the inventory. That will allow analysis of uncertainty about the extent to which individual calculation methods are correct, and WP's 2.9-11 are likely to provide information on input factors that can partly be used in the current calculation methods as well. Many of the other WP2-activities can contribute calibration data, which can be used in the Bayesian approach to calculate the likelihood for different values of input factors.

However, in the short term the UQ in WP3 largely depends on other sources of information. These include literature data on measurements of input and output variables, default uncertainties provided by the IPCC (as discussed above) and expert judgement primarily provided by the project partners. Furthermore, detailed examples of UQ associated with the LULUCF sector of the GHG inventory in Finland have been provided by Peltoniemi *et al.* (2006) and Monni *et al.* (2007). These include uncertainty quantifications – with specification of the type of pdf (normal, lognormal, triangular or uniform) - of more than 60 parameters included in the calculation of forest biomass and soil C-stock, many of which can be adapted for use in the UK, i.e. in WP3. Among the regular sources of biogeochemical data – from international projects and databases – we only mention further the IPCC Emission Factor Database (http://www.ipcc-nggip.iges.or.jp/EFDB/main.php) which currently mainly holds default IPCC values but is expected to be of increasing importance over the coming years.

20.4 Outlook

The work in year 1 has put the methodology for uncertainty quantification in place, and sufficient sources of information on input factors for the inventory calculation were identified to allow the first practical tests of the approach. That will be the main the task for year 2 of the project.

20.5 References

Monni, S., M. Peltoniemi, T. Palosuo, A. Lehtonen, R. Makipaa and I. Savolainen. 2007. Uncertainty of forest carbon stock changes - implications to the total uncertainty of GHG inventory of Finland. *Climate Change*. **81**:391-413.

Patenaude, G., Van Oijen, M., Milne, R., Dawson, T. (2005) Quantifying uncertainty in forest carbon modelling with Bayesian statistics. IUFRO sustainable forestry in theory and practice. 5 to 8 April 2005, Edinburgh-Scotland, UK.

Peltoniemi, M., T. Palosuo, S. Monni and R. Makipaa. 2006. Factors affecting the uncertainty of sinks and stocks of carbon in Finnish forests soils and vegetation. *Forest Ecology and Management*. **232**:75-85.

Van Oijen, M. and NitroEurope modellers (2006). “Protocol-UQ/UA”: A protocol for uncertainty quantification and uncertainty analysis of models used in NEU. NitroEurope publication: 6 pp.

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 have maintained regular communication with AEA, the contractor responsible for the total UK inventory. We also contributed to the week-long UN in-country review of the UK's inventory and initial report under the Kyoto Protocol in March 2007, and responded to all of the reviewer's questions in a comprehensive and timely fashion. We also responded as required to the UN desk-based review of the inventory in January 2007.

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 2006/07 project year.

21.2.1 National collaborations

ECOSSE

This research project was led by the University of Aberdeen, with the Macaulay Institute, CEH, NSRI and Rothamsted Research as project partners, and was funded by the Scottish Executive and the Welsh Assembly Government. The aims of the project were: (1) to develop a new model of C and N dynamics that reflects conditions in organic soils in Scotland and Wales and predicts their likely responses to external factors; (2) to identify the extent of soils that can be considered organic in Scotland and Wales and provide an estimate of the carbon contained within them; and (3) to predict the contribution of CO_2, nitrous oxide and methane emissions from organic soils in Scotland and Wales, and provide advice on how changes in land use and climate will affect the C and N balance.

CEH Edinburgh's contribution to this work was the development of more spatially and temporally detailed land use change matrices for Scotland and Wales. These matrices will be incorporated into the inventory methods, and equivalent land use change matrices are also being developed for England.

The ECOSSE model developed by the University of Aberdeen is of great interest to the inventory (see chapter 13, WP 2.9 and 2.10). Further information is available from the ECOSSE project final report.

Smith, P., Smith, J.U., Flynn, H., Killham, K., Rangel-Castro, I., Foereid, B., Aitkenhead, M., Chapman, S., Towers, W., Bell, J., Lumsdon, D., Milne, R., Thomson, A., Simmons, I., Skiba, U., Reynolds, B., Evans, C., Frogbrook, Z., Bradley, I., Whitmore, A., Falloon, P. 2007d. *ECOSSE: Estimating Carbon in Organic Soils - Sequestration and Emissions. Final Report*. SEERAD Report. ISBN 978 0 7559 1498 2. 166pp.

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).

Forestry collaborations

Ronnie Milne has collaborated with staff at the National Forest and at the Forestry Commission to produce projections of woodland carbon sequestration at small scales.

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. There is also the potential for collaboration with the French LULUCF technical experts on estimates for overseas territories in the Caribbean.

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 2006 and May 2007 are listed below.

22.1 Meetings/presentations

- Internal CEH carbon and nitrogen modelling workshop, Bangor, June 2006 (A. Thomson, D. Mobbs, M. van Oijen)
- Presentation at CEH Soils Workshop, Lancaster, June 2006 (P.Levy)
- British Soil Science Society conference on "Soils, vegetation and climate change", Leeds, September 2006 (A. Thomson, U. Skiba)
- IPCC Emissions Factor Database Editorial Board meeting, Sao Paulo, Brazil, September 2006 (A. Thomson successfully nominated by Defra to be an editorial board member of the IPCC EFDB).
- Defra Soil Carbon Experts' Workshop, Reading, October 2006 (M. Billett)
- "Technical meeting on specific forestry issues related to reporting and accounting under the Kyoto Protocol" at JRC Ispra in November 2006: attended and presented on the UK experience in this field (A. Thomson)
- IPCC meeting on "Future work programme of the IPCC Taskforce on GHG Inventories", Geneva, Switzerland, January 2007 (A. Thomson)
- Talk on land use, forestry and climate change to the Peebles Farmer's Discussion Society, February 2007 (A. Thomson)
- Stakeholders meeting at the Environmental Research Institute, Thurso, Feb 2007 (P. Levy, M. Billett)
- Presentation on LULUCF work to New Zealand expert for Scottish Executive, May 2007 (A. Thomson)

22.2 Requests for information/advice

CEH responded to a large number of requests for advice/information from Defra, the media, 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: Progress report to EU on measures to reduce GHG emissions (forestry section)
- Defra: Comments on the Kyoto Protocol reporting tables for the EU joint submission
- Defra: Query on fen soil carbon losses in the inventory
- Defra: Parliamentary question on studies on the degradation of peat bogs (PQ 22274)
- Defra: Requested comments on tender for projections of future land use change
- Defra: Carbon sequestration in the England Forestry Strategy
- Defra: Response to New Scientist article on grouse moor burning
- Defra: Information on peat extraction
- Defra: Parliamentary question on deforestation and CO_2 (PQ 0237)
- Defra: Bi-annual science report summary
- Defra; Reviewer for WG3 4th Assessment Report of the IPCC
- Defra: Contribution to Secretary of State briefing on forestry and climate change
- Defra: Information for Environmental Audit committee on carbon offsetting

- Northern Ireland: Enquiries on data sources for the inventory (2 separate queries)
- Forestry Commission Scotland: Enquiry on forest carbon estimates for the Scottish Climate Change Programme
- Natural England: Enquiry on peat soil extents
- Public: Queries on carbon offsetting from forestry (8 separate queries)
- Countryside Land and Business Association (CLA): Farm-level GHG emissions accounting
- Independent sub-contractor for the Forestry Commission: Query on carbon footprints of forestry operations
- Policy Studies Institute: Phone interview on LULUCF issues for FC review
- Scottish Executive: Summary report on LULUCF methods and numbers
- Netherlands query on UK's estimate for Article 3.7 of the Kyoto Protocol
- Media: Query on Scottish forestry inventory estimates by the Scotsman

22.3 Publications

Baggott, S.L., Cardenas, L., Downes, M., Garnett, E., Jackson, J., Li, Y., Passant, N., and Thomson, A. (2006). *Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 - 2004*. AEAT/ENV/R/2318 08/11/2006.

Baggott, S., Cardenas, L., Garnett, E., Jackson, J., Mobbs, D.C., Murrells, T., Passant, N., Thomson, A., and Watterson, J. (2007) *UK Greenhouse Gas Inventory, 1990 to 2005: Annual Report for submission under the Framework Convention on Climate Change*. AEAT/ENV/R/2429

Briones, M.J.I., Ineson, P., Heinemeyer, A. Predicting potential impacts of climate change on the geographical distribution of enchytraeids: a meta-analysis approach. *Global Change Biology*, (accepted).

Defra. 2006. The UK's initial report under the Kyoto protocol. http://unfccc.int/files/national_reports/initial_reports_under_the_kyoto_protocol/application/pdf/report_final.pdf

Halsall, L., Gilbert, J., Matthews, R. and Fairgrieve, M. (2006) United Kingdom: New Forecast of Softwood Availability. *Forestry and British Timber* **35(11),** pp14-23. Novmeber 2006

Hartley I.P., Armstrong A.F., Murthyw R., Barron-Gafford G., Ineson P. and Atkin O.K. (2006) The dependence of respiration on photosynthetic substrate supply and temperature: integrating leaf, soil and ecosystem measurements. Global Change Biology **12** 1954-1968.

Hartley, I.P., Heinemeyer, A., and Ineson. P. (in press a) Effects of three years of soil warming and shading on the rate of soil respiration: substrate availability and not thermal acclimation mediates observed response. *Global Change Biology*.

Hartley, I.P., Heinemeyer, A., Evans, S.P., and Ineson. P. (in press b). The effect of soil warming on bulk soil versus rhizosphere respiration. *Global Change Biology*.

Heinemeyer, A., Ineson, P., Ostle, N. and Fitter A.H. (2006). Respiration of the external mycelium in the arbuscular mycorrhizal symbiosis shows strong dependence on recent photosynthates and acclimation to temperature. *New Phytologist* **171**: 159-170.

Heinemeyer, A., Hartley, I.P., Evans, S.P., Carreira de la Fuente, J.A. and Ineson, P. (in press). Forest soil CO_2 flux: uncovering the contribution and environmental responses of ectomycorrhizas. *Global Change Biology*.

Kennedy, M.C., Anderson, C.W., Heinemeyer, A., Lomas, M.R., O'Hagan, A., Quegan, S., and Woodward, F.I. (in press). Quantifying Uncertainty in the Biospheric Carbon Flux for England and Wales. *Journal Royal Statistical Society*.

Matthews, R.W., Robertson, K., Marland, G. and Marland, E. (2007) Carbon in wood products and product substitution. In: Freer-Smith, P.H., Broadmeadow, M.S.J. and Lynch, J.M. (eds). *Forestry and Climate Change*. CAB International: Wallingford, 91-104. (In press.)

Magnani F, Mencuccini M, Borghetti M, Grace J and 17 others (2007) The human footprint in the carbon cycle of established temperate and boreal forest. *Nature* ***, **-** (to be published 14th June 2007)

Quaife, T., Lewis, P., De Kauwe, M., Williams, M., Law, B.E., Disney, M. and Bowyer, P. (2007), in press. Assimilating Canopy Reflectance data into an Ecosystem Model with an Ensemble Kalman Filter. *Remote Sensing of Environment*.

23. Provision of an archive of the LULUCF inventory and projections (WP 6)

D. C. Mobbs
Centre for Ecology & Hydrology, Bush Estate, Penicuik

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 1990-2005.

CEH has an inventory manual for internal use, which is updated with any new data or 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 2005 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	**2882**	**-12203**	**15836**	**-6200**	**6904**	**-1456**
1991	2755	-12715	15996	-6152	6836	-1210
1992	2251	-13340	16001	-6261	6770	-920
1993	1068	-13714	15577	-6671	6718	-842
1994	863	-14193	15631	-6614	6671	-633
1995	**992**	**-13948**	**15771**	**-6541**	**6610**	**-900**
1996	850	-13720	15803	-6789	6578	-1021
1997	502	-13512	15543	-6893	6560	-1197
1998	-53	-13406	15428	-7291	6521	-1306
1999	-267	-13504	15329	-7283	6458	-1268
2000	**-449**	**-13805**	**15339**	**-7446**	**6413**	**-950**
2001	-603	-14348	15287	-7470	6374	-445
2002	-1124	-15045	15313	-7766	6327	47
2003	-1181	-15646	15384	-7559	6302	337
2004	-1935	-16302	15316	-7858	6291	619
2005	**-2056**	**-15738**	**15258**	**-7934**	**6262**	**96**
2006	*-2394*	*-15239*	*15172*	*-8203*	*6231*	*-354*
2007	*-2258*	*-14333*	*15158*	*-8179*	*6229*	*-1133*
2008	*-2238*	*-13791*	*15254*	*-8326*	*6220*	*-1595*
2009	*-2052*	*-12936*	*15269*	*-8319*	*6194*	*-2259*
2010	***-1554***	***-10776***	***15247***	***-8498***	***6171***	***-3698***
2011	*-1159*	*-10711*	*15225*	*-8582*	*6165*	*-3256*
2012	*-750*	*-9957*	*15212*	*-8653*	*6151*	*-3503*
2013	*-385*	*-8961*	*15186*	*-8723*	*6137*	*-4025*
2014	*-77*	*-8546*	*15186*	*-8847*	*6126*	*-3995*
2015	***488***	***-7835***	***15229***	***-8916***	***6118***	***-4108***
2016	*857*	*-7725*	*15226*	*-8983*	*6105*	*-3766*
2017	*1138*	*-7749*	*15259*	*-9112*	*6101*	*-3362*
2018	*1244*	*-7750*	*15192*	*-9219*	*6098*	*-3076*
2019	*1494*	*-6789*	*15166*	*-9324*	*6088*	*-3647*
2020	***2223***	***-5045***	***15181***	***-9333***	***6079***	***-4658***

B (Low) UK Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2005	**-2056**	**-15738**	**15258**	**-7934**	**6262**	**96**
2006	-2760	*-15206*	*14930*	*-8295*	*6165*	*-354*
2007	-2917	*-14180*	*14690*	*-8393*	*6099*	*-1133*
2008	-3247	*-13607*	*14570*	*-8647*	*6032*	*-1595*
2009	-3500	*-12818*	*14380*	*-8752*	*5949*	*-2259*
2010	-3294	*-10813*	*14286*	*-8974*	*5906*	*-3698*
2011	-3356	*-10969*	*14132*	*-9133*	*5870*	*-3256*
2012	-3484	*-10461*	*13954*	*-9296*	*5822*	*-3503*
2013	-3671	*-9710*	*13750*	*-9459*	*5772*	*-4025*
2014	-3852	*-9528*	*13584*	*-9632*	*5718*	*-3995*
2015	-3850	*-9034*	*13434*	*-9811*	*5669*	*-4108*
2016	-3968	*-9127*	*13268*	*-9958*	*5616*	*-3766*
2017	-4171	*-9344*	*13127*	*-10199*	*5607*	*-3362*
2018	-4484	*-9531*	*12911*	*-10338*	*5551*	*-3076*
2019	-4705	*-8751*	*12719*	*-10521*	*5494*	*-3647*
2020	-4460	*-7186*	*12563*	*-10623*	*5443*	*-4658*

C (High) UK Gg CO_2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2005	**-2056**	**-15738**	**15258**	**-7934**	**6262**	**96**
2006	*-1984*	*-15260*	*15413*	*-8081*	*6298*	*-354*
2007	*-1544*	*-14426*	*15625*	*-7969*	*6360*	*-1133*
2008	*-1162*	*-13901*	*15935*	*-8011*	*6410*	*-1595*
2009	*-577*	*-13008*	*16156*	*-7909*	*6442*	*-2259*
2010	*207*	*-10753*	*16229*	*-8015*	*6444*	*-3698*
2011	*961*	*-10556*	*16320*	*-8019*	*6473*	*-3256*
2012	*1769*	*-9653*	*16443*	*-8017*	*6500*	*-3503*
2013	*2558*	*-8509*	*16572*	*-8007*	*6528*	*-4025*
2014	*3359*	*-7955*	*16750*	*-8010*	*6569*	*-3995*
2015	*4338*	*-7113*	*16957*	*-8009*	*6611*	*-4108*
2016	*5122*	*-6880*	*17112*	*-7991*	*6648*	*-3766*
2017	*5821*	*-6788*	*17314*	*-8034*	*6690*	*-3362*
2018	*6374*	*-6677*	*17401*	*-8006*	*6732*	*-3076*
2019	*6983*	*-5606*	*17516*	*-8051*	*6771*	*-3647*
2020	*8138*	*-3754*	*17691*	*-7945*	*6805*	*-4658*

Table A1. 2: England data for 2005 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 CO2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**5712**	**-2733**	**7508**	**-2597**	**3895**	**-361**
1991	5818	-2775	7595	-2554	3838	-285
1992	5644	-2856	7560	-2636	3782	-206
1993	4996	-2851	7177	-2856	3737	-211
1994	4993	-2889	7183	-2820	3697	-177
1995	**5081**	**-2825**	**7258**	**-2779**	**3646**	**-219**
1996	4891	-2894	7247	-2917	3617	-162
1997	4552	-2872	7003	-2965	3598	-212
1998	4163	-2818	6877	-3177	3564	-284
1999	3991	-2874	6764	-3160	3513	-252
2000	**3908**	**-2760**	**6742**	**-3219**	**3475**	**-330**
2001	3842	-2946	6658	-3163	3442	-149
2002	3552	-3169	6662	-3373	3403	29
2003	3563	-3333	6695	-3312	3381	133
2004	3259	-3540	6615	-3437	3368	253
2005	**3079**	**-3448**	**6545**	**-3511**	**3343**	**150**
2006	*2844*	*-3316*	*6452*	*-3622*	*3317*	*13*
2007	*2845*	*-2969*	*6417*	*-3612*	*3312*	*-302*
2008	*2867*	*-2733*	*6473*	*-3680*	*3301*	*-495*
2009	*2893*	*-2476*	*6463*	*-3681*	*3279*	*-693*
2010	***2860***	***-2249***	***6425***	***-3778***	***3259***	***-796***
2011	*2813*	*-2374*	*6389*	*-3851*	*3251*	*-602*
2012	*2822*	*-2187*	*6362*	*-3881*	*3238*	*-709*
2013	*2889*	*-1503*	*6325*	*-3906*	*3225*	*-1252*
2014	*2902*	*-1449*	*6310*	*-3966*	*3214*	*-1206*
2015	***3028***	***-1271***	***6329***	***-3994***	***3205***	***-1241***
2016	*3057*	*-1251*	*6313*	*-4033*	*3193*	*-1165*
2017	*3062*	*-1333*	*6325*	*-4104*	*3188*	*-1013*
2018	*2997*	*-1402*	*6257*	*-4150*	*3183*	*-891*
2019	*2930*	*-1373*	*6223*	*-4203*	*3173*	*-890*
2020	***3067***	***-805***	***6222***	***-4216***	***3165***	***-1299***

B (Low) England Gg CO2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2005	**3079**	**-3448**	**6545**	**-3511**	**3343**	**150**
2006	*2634*	*-3318*	*6337*	*-3679*	*3282*	*13*
2007	*2462*	*-2953*	*6195*	*-3722*	*3243*	*-302*
2008	*2276*	*-2731*	*6148*	*-3849*	*3202*	*-495*
2009	*2067*	*-2523*	*6040*	*-3909*	*3150*	*-693*
2010	*1857*	*-2379*	*5951*	*-4037*	*3118*	*-796*
2011	*1571*	*-2611*	*5833*	*-4145*	*3096*	*-602*
2012	*1312*	*-2539*	*5713*	*-4217*	*3065*	*-709*
2013	*1099*	*-1968*	*5580*	*-4296*	*3034*	*-1252*
2014	*855*	*-2019*	*5482*	*-4403*	*3001*	*-1206*
2015	*714*	*-1940*	*5404*	*-4481*	*2971*	*-1241*
2016	*515*	*-2010*	*5307*	*-4558*	*2941*	*-1165*
2017	*279*	*-2178*	*5234*	*-4705*	*2942*	*-1013*
2018	*22*	*-2329*	*5099*	*-4767*	*2909*	*-891*
2019	*-279*	*-2378*	*4978*	*-4864*	*2876*	*-890*
2020	*-372*	*-1888*	*4880*	*-4910*	*2845*	*-1299*

C (High) England Gg CO2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2005	**3079**	**-3448**	**6545**	**-3511**	**3343**	**150**
2006	*3052*	*-3315*	*6567*	*-3566*	*3353*	*13*
2007	*3245*	*-2978*	*6640*	*-3496*	*3381*	*-302*
2008	*3462*	*-2734*	*6798*	*-3509*	*3402*	*-495*
2009	*3701*	*-2448*	*6888*	*-3457*	*3412*	*-693*
2010	*3817*	*-2171*	*6903*	*-3524*	*3406*	*-796*
2011	*3960*	*-2232*	*6926*	*-3548*	*3417*	*-602*
2012	*4171*	*-1975*	*6960*	*-3531*	*3426*	*-709*
2013	*4439*	*-1223*	*6994*	*-3515*	*3435*	*-1252*
2014	*4664*	*-1105*	*7054*	*-3530*	*3452*	*-1206*
2015	*4997*	*-869*	*7147*	*-3508*	*3468*	*-1241*
2016	*5230*	*-793*	*7202*	*-3495*	*3481*	*-1165*
2017	*5440*	*-824*	*7295*	*-3517*	*3500*	*-1013*
2018	*5573*	*-844*	*7294*	*-3505*	*3518*	*-891*
2019	*5684*	*-767*	*7320*	*-3513*	*3534*	*-890*
2020	*6020*	*-152*	*7391*	*-3465*	*3546*	*-1299*

Table A1. 3: Scotland data for 2005 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 CO2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**-2541**	**-7547**	**6104**	**-2119**	**1736**	**-714**
1991	-2813	-7951	6178	-2132	1728	-635
1992	-3110	-8365	6225	-2143	1719	-546
1993	-3541	-8714	6199	-2245	1714	-495
1994	-3730	-9062	6250	-2222	1709	-406
1995	**-3720**	**-8973**	**6316**	**-2198**	**1701**	**-567**
1996	-3681	-8860	6362	-2274	1699	-607
1997	-3727	-8837	6357	-2331	1700	-615
1998	-3867	-8878	6374	-2451	1696	-607
1999	-3937	-9075	6393	-2425	1686	-516
2000	**-3944**	**-8869**	**6427**	**-2483**	**1680**	**-699**
2001	-4017	-9164	6462	-2559	1675	-431
2002	-4195	-9611	6486	-2616	1668	-122
2003	-4244	-10054	6525	-2474	1666	93
2004	-4649	-10473	6539	-2629	1666	247
2005	**-4581**	**-10133**	**6554**	**-2596**	**1663**	**-69**
2006	*-4684*	*-9803*	*6565*	*-2726*	*1659*	*-379*
2007	*-4563*	*-9375*	*6587*	*-2694*	*1661*	*-742*
2008	*-4603*	*-9227*	*6626*	*-2777*	*1662*	*-887*
2009	*-4472*	*-8754*	*6651*	*-2759*	*1659*	*-1269*
2010	***-4110***	***-7649***	***6669***	***-2827***	***1656***	***-1959***
2011	*-3785*	*-7556*	*6683*	*-2819*	*1657*	*-1750*
2012	*-3468*	*-6975*	*6699*	*-2844*	*1656*	*-2004*
2013	*-3240*	*-6686*	*6712*	*-2872*	*1655*	*-2050*
2014	*-3018*	*-6373*	*6728*	*-2923*	*1655*	*-2105*
2015	***-2703***	***-6024***	***6751***	***-2958***	***1655***	***-2126***
2016	*-2453*	*-6023*	*6765*	*-2974*	*1654*	*-1875*
2017	*-2270*	*-6150*	*6785*	*-3025*	*1655*	*-1536*
2018	*-2163*	*-6152*	*6788*	*-3063*	*1656*	*-1391*
2019	*-1946*	*-5482*	*6797*	*-3099*	*1655*	*-1817*
2020	***-1527***	***-4670***	***6812***	***-3087***	***1655***	***-2237***

B (Low) Scotland **Gg CO2/year**	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2005	**-4581**	**-10133**	**6554**	**-2596**	**1663**	**-69**
2006	*-4778*	*-9769*	*6466*	*-2737*	*1641*	*-379*
2007	*-4723*	*-9248*	*6394*	*-2753*	*1626*	*-742*
2008	*-4848*	*-9058*	*6345*	*-2860*	*1611*	*-887*
2009	*-4861*	*-8595*	*6286*	*-2875*	*1592*	*-1269*
2010	*-4577*	*-7550*	*6290*	*-2944*	*1585*	*-1959*
2011	*-4417*	*-7553*	*6270*	*-2961*	*1577*	*-1750*
2012	*-4309*	*-7083*	*6231*	*-3020*	*1568*	*-2004*
2013	*-4292*	*-6906*	*6179*	*-3071*	*1556*	*-2050*
2014	*-4241*	*-6701*	*6130*	*-3109*	*1545*	*-2105*
2015	*-4158*	*-6454*	*6078*	*-3189*	*1534*	*-2126*
2016	*-4109*	*-6549*	*6027*	*-3234*	*1521*	*-1875*
2017	*-4110*	*-6768*	*5979*	*-3304*	*1518*	*-1536*
2018	*-4173*	*-6860*	*5920*	*-3347*	*1504*	*-1391*
2019	*-4138*	*-6277*	*5868*	*-3401*	*1490*	*-1817*
2020	*-3916*	*-5553*	*5828*	*-3432*	*1478*	*-2237*

C (High) Scotland **Gg CO2/year**	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
2005	**-4581**	**-10133**	**6554**	**-2596**	**1663**	**-69**
2006	*-4546*	*-9823*	*6662*	*-2683*	*1677*	*-379*
2007	*-4368*	*-9451*	*6776*	*-2647*	*1696*	*-742*
2008	*-4301*	*-9329*	*6902*	*-2699*	*1712*	*-887*
2009	*-4046*	*-8850*	*7009*	*-2661*	*1724*	*-1269*
2010	*-3574*	*-7709*	*7062*	*-2695*	*1728*	*-1959*
2011	*-3122*	*-7559*	*7119*	*-2672*	*1739*	*-1750*
2012	*-2659*	*-6911*	*7193*	*-2687*	*1749*	*-2004*
2013	*-2264*	*-6553*	*7272*	*-2692*	*1759*	*-2050*
2014	*-1821*	*-6175*	*7371*	*-2686*	*1773*	*-2105*
2015	*-1357*	*-5765*	*7465*	*-2719*	*1788*	*-2126*
2016	*-952*	*-5706*	*7544*	*-2718*	*1803*	*-1875*
2017	*-614*	*-5777*	*7633*	*-2751*	*1816*	*-1536*
2018	*-313*	*-5726*	*7706*	*-2731*	*1829*	*-1391*
2019	*29*	*-5003*	*7778*	*-2772*	*1844*	*-1817*
2020	*619*	*-4137*	*7863*	*-2725*	*1854*	*-2237*

Table A1. 4: Wales data for 2005 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 CO2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**-244**	**-1178**	**969**	**-403**	**704**	**-336**
1991	-204	-1246	978	-393	701	-244
1992	-206	-1358	985	-401	699	-130
1993	-260	-1432	986	-451	698	-62
1994	-261	-1491	993	-452	697	-7
1995	**-223**	**-1427**	**1001**	**-448**	**695**	**-42**
1996	-183	-1247	1006	-466	694	-170
1997	-131	-1083	1008	-466	694	-286
1998	-124	-1001	1012	-502	693	-326
1999	-72	-837	1016	-519	691	-423
2000	**-134**	**-1441**	**1021**	**-543**	**690**	**139**
2001	-138	-1477	1024	-545	689	171
2002	-174	-1522	1029	-562	687	193
2003	-204	-1559	1035	-559	687	192
2004	-244	-1584	1038	-570	687	185
2005	**-247**	**-1509**	**1041**	**-588**	**687**	**124**
2006	*-239*	*-1491*	*1044*	*-605*	*686*	*127*
2007	*-234*	*-1430*	*1047*	*-615*	*687*	*77*
2008	*-223*	*-1321*	*1052*	*-614*	*687*	*-27*
2009	*-211*	*-1214*	*1055*	*-619*	*687*	*-121*
2010	***-48***	***-327***	***1058***	***-627***	***686***	***-838***
2011	*58*	*-284*	*1061*	*-637*	*687*	*-768*
2012	*129*	*-349*	*1063*	*-646*	*687*	*-626*
2013	*177*	*-369*	*1065*	*-657*	*687*	*-549*
2014	*235*	*-325*	*1068*	*-664*	*687*	*-532*
2015	***334***	***-216***	***1071***	***-667***	***687***	***-542***
2016	*393*	*-199*	*1073*	*-674*	*687*	*-494*
2017	*449*	*-146*	*1076*	*-678*	*687*	*-490*
2018	*479*	*-129*	*1077*	*-691*	*688*	*-465*
2019	*551*	*117*	*1079*	*-700*	*688*	*-633*
2020	***689***	***428***	***1081***	***-705***	***688***	***-804***

B (Low) Wales Gg CO2/year	5 NET	5A Forestland	5B Cropland	5C Grassland	5E Settlements	5G HWP
2005	**-247**	**-1509**	**1041**	**-588**	**687**	**124**
2006	*-271*	*-1491*	*1029*	*-614*	*678*	*127*
2007	*-295*	*-1428*	*1018*	*-634*	*672*	*77*
2008	*-315*	*-1321*	*1009*	*-642*	*666*	*-27*
2009	*-336*	*-1219*	*1000*	*-656*	*659*	*-121*
2010	*-194*	*-342*	*999*	*-668*	*655*	*-838*
2011	*-118*	*-311*	*994*	*-686*	*652*	*-768*
2012	*-80*	*-388*	*988*	*-702*	*648*	*-626*
2013	*-66*	*-421*	*979*	*-718*	*644*	*-549*
2014	*-41*	*-389*	*972*	*-732*	*638*	*-532*
2015	*22*	*-291*	*964*	*-742*	*633*	*-542*
2016	*52*	*-285*	*956*	*-754*	*628*	*-494*
2017	*75*	*-242*	*947*	*-766*	*626*	*-490*
2018	*76*	*-234*	*938*	*-783*	*620*	*-465*
2019	*117*	*4*	*930*	*-797*	*615*	*-633*
2020	*224*	*306*	*921*	*-809*	*610*	*-804*

C (High) Wales Gg CO2/year	5 NET	5A Forestland	5B Cropland	5C Grassland	5E Settlements	5G HWP
2005	**-247**	**-1509**	**1041**	**-588**	**687**	**124**
2006	*-206*	*-1491*	*1059*	*-595*	*694*	*127*
2007	*-171*	*-1431*	*1078*	*-596*	*702*	*77*
2008	*-129*	*-1321*	*1096*	*-586*	*709*	*-27*
2009	*-85*	*-1210*	*1113*	*-582*	*715*	*-121*
2010	*94*	*-318*	*1118*	*-585*	*718*	*-838*
2011	*224*	*-268*	*1127*	*-590*	*722*	*-768*
2012	*324*	*-325*	*1140*	*-592*	*727*	*-626*
2013	*402*	*-337*	*1151*	*-594*	*731*	*-549*
2014	*491*	*-286*	*1165*	*-593*	*737*	*-532*
2015	*621*	*-170*	*1179*	*-589*	*743*	*-542*
2016	*711*	*-147*	*1193*	*-589*	*748*	*-494*
2017	*796*	*-89*	*1206*	*-585*	*754*	*-490*
2018	*855*	*-66*	*1217*	*-590*	*760*	*-465*
2019	*955*	*186*	*1228*	*-591*	*765*	*-633*
2020	*1121*	*502*	*1240*	*-588*	*771*	*-804*

Table A1. 5: Northern Ireland data for 2005 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 CO2/year	**5 NET**	**5A Forestland**	**5B Cropland**	**5C Grassland**	**5E Settlements**	**5G HWP**
1990	**-45**	**-744**	**1255**	**-1081**	**570**	**-45**
1991	-47	-742	1244	-1073	569	-46
1992	-78	-761	1232	-1081	569	-37
1993	-126	-718	1216	-1119	569	-74
1994	-139	-750	1205	-1120	569	-43
1995	**-146**	**-723**	**1196**	**-1116**	**568**	**-72**
1996	-177	-719	1187	-1131	568	-82
1997	-192	-721	1175	-1131	568	-84
1998	-225	-709	1165	-1161	568	-89
1999	-249	-718	1157	-1179	568	-77
2000	**-278**	**-736**	**1149**	**-1201**	**568**	**-60**
2001	-290	-762	1142	-1204	569	-35
2002	-308	-744	1135	-1216	569	-53
2003	-296	-700	1130	-1215	569	-80
2004	-300	-705	1124	-1222	569	-66
2005	**-308**	**-648**	**1118**	**-1238**	**569**	**-108**
2006	*-315*	*-630*	*1112*	*-1251*	*569*	*-115*
2007	*-307*	*-560*	*1107*	*-1257*	*569*	*-166*
2008	*-279*	*-509*	*1104*	*-1256*	*569*	*-187*
2009	*-261*	*-493*	*1100*	*-1260*	*570*	*-177*
2010	***-256***	***-550***	***1095***	***-1267***	***570***	***-104***
2011	*-245*	*-496*	*1091*	*-1274*	*570*	*-135*
2012	*-233*	*-446*	*1088*	*-1281*	*570*	*-164*
2013	*-211*	*-403*	*1084*	*-1289*	*570*	*-173*
2014	*-196*	*-400*	*1081*	*-1294*	*570*	*-153*
2015	***-171***	***-324***	***1078***	***-1297***	***570***	***-199***
2016	*-141*	*-253*	*1075*	*-1302*	*571*	*-233*
2017	*-103*	*-120*	*1073*	*-1305*	*571*	*-322*
2018	*-70*	*-66*	*1070*	*-1315*	*571*	*-329*
2019	*-41*	*-51*	*1067*	*-1322*	*571*	*-306*
2020	***-5***	***2***	***1065***	***-1325***	***571***	***-318***

B (Low) **N. Ireland** **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**
2005	**-308**	**-648**	**1118**	**-1238**	**569**	**-108**
2006	*-345*	*-627*	*1099*	*-1265*	*563*	*-115*
2007	*-361*	*-551*	*1083*	*-1285*	*558*	*-166*
2008	*-360*	*-498*	*1068*	*-1296*	*552*	*-187*
2009	*-370*	*-481*	*1054*	*-1313*	*548*	*-177*
2010	*-379*	*-543*	*1046*	*-1325*	*547*	*-104*
2011	*-392*	*-494*	*1035*	*-1342*	*545*	*-135*
2012	*-407*	*-451*	*1023*	*-1357*	*542*	*-164*
2013	*-412*	*-415*	*1012*	*-1374*	*538*	*-173*
2014	*-425*	*-419*	*1000*	*-1388*	*534*	*-153*
2015	*-428*	*-349*	*989*	*-1400*	*531*	*-199*
2016	*-426*	*-283*	*977*	*-1413*	*525*	*-233*
2017	*-415*	*-157*	*966*	*-1424*	*522*	*-322*
2018	*-409*	*-108*	*953*	*-1442*	*517*	*-329*
2019	*-406*	*-98*	*943*	*-1458*	*514*	*-306*
2020	*-396*	*-51*	*934*	*-1472*	*510*	*-318*

C (High) **N. Ireland** **Gg CO2/year**	**5** **NET**	**5A** **Forestland**	**5B** **Cropland**	**5C** **Grassland**	**5E** **Settlements**	**5G** **HWP**
2005	**-308**	**-648**	**1118**	**-1238**	**569**	**-108**
2006	*-285*	*-631*	*1124*	*-1237*	*575*	*-115*
2007	*-250*	*-565*	*1131*	*-1231*	*581*	*-166*
2008	*-195*	*-516*	*1139*	*-1217*	*586*	*-187*
2009	*-148*	*-499*	*1145*	*-1209*	*591*	*-177*
2010	*-130*	*-555*	*1146*	*-1211*	*593*	*-104*
2011	*-100*	*-497*	*1147*	*-1210*	*595*	*-135*
2012	*-66*	*-443*	*1150*	*-1208*	*598*	*-164*
2013	*-17*	*-396*	*1155*	*-1206*	*603*	*-173*
2014	*25*	*-389*	*1161*	*-1201*	*607*	*-153*
2015	*76*	*-309*	*1166*	*-1193*	*612*	*-199*
2016	*133*	*-234*	*1173*	*-1189*	*616*	*-233*
2017	*199*	*-98*	*1179*	*-1180*	*620*	*-322*
2018	*258*	*-41*	*1184*	*-1180*	*625*	*-329*
2019	*315*	*-22*	*1191*	*-1175*	*628*	*-306*
2020	*378*	*33*	*1197*	*-1168*	*633*	*-318*

24.2 Appendix 2: Sectoral Tables for Land Use Change and Forestry Sector as submitted for the UK 2005 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	**2,881.5591**	**0.5919**	**0.0041**	**0.1471**	**5.1795**
A. Forest Land	**-12,202.5700**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-12,202.5700	NE,NO	NE,NO	NO	NO
B. Cropland	**15,836.0403**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	1,009.6086	NA	NA	NO	NO
2. Land converted to Cropland	14,033.9810	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,200.2472**	**0.1465**	**0.0010**	**0.0364**	**1.2822**
1. Grassland remaining Grassland	389.5392	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,227.7822	0.1465	0.0010	0.0364	1.2822
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,904.2192**	**0.4454**	**0.0031**	**0.1107**	**3.8973**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,802.1461	IE	IE	0.1107	3.8973
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,455.8832**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,455.8832	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	318.7972	0.5919	0.0041	0.1471	5.1795
Grassland converted to other Land-Use Categories	NO	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	**2,754.5456**	**0.5587**	**0.0038**	**0.1388**	**4.8889**
A. Forest Land	**-12,714.6301**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-12,714.6301	NE,NO	NE,NO	NO	NO
B. Cropland	**15,995.5301**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	972.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,048.1452	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,151.9332**	**0.1564**	**0.0011**	**0.0389**	**1.3689**
1. Grassland remaining Grassland	396.2563	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,345.6970	0.1564	0.0011	0.0389	1.3689
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,835.7741**	**0.4023**	**0.0028**	**0.1000**	**3.5201**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,743.5819	IE	IE	0.1000	3.5201
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,210.1952**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,210.1952	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	318.5280	0.5587	0.0038	0.1388	4.8889
Grassland converted to other Land-Use Categories	NO	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	**2,250.8431**	**0.5311**	**0.0037**	**0.1320**	**4.6474**
A. Forest Land	**-13,340.0878**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,340.0878	NE,NO	NE,NO	NO	NO
B. Cropland	**16,001.1031**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	936.2752	NA	NA	NO	NO
2. Land converted to Cropland	14,063.2865	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,260.5295**	**0.1712**	**0.0012**	**0.0425**	**1.4978**
1. Grassland remaining Grassland	389.7208	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,458.2926	0.1712	0.0012	0.0425	1.4978
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,769.9590**	**0.3599**	**0.0025**	**0.0894**	**3.1495**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,687.4713	IE	IE	0.0894	3.1495
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-919.6018**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-919.6018	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	319.1308	0.5311	0.0037	0.1320	4.6474
Grassland converted to other Land-Use Categories	NO	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	**1,068.2401**	**0.4727**	**0.0033**	**0.1175**	**4.1360**
A. Forest Land	**-13,714.0704**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,714.0704	NE,NO	NE,NO	NO	NO
B. Cropland	**15,577.2424**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	899.6086	NA	NA	NO	NO
2. Land converted to Cropland	14,079.2387	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,670.6443**	**0.1310**	**0.0009**	**0.0326**	**1.1465**
1. Grassland remaining Grassland	382.6404	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,585.2120	0.1310	0.0009	0.0326	1.1465
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,717.7063**	**0.3417**	**0.0023**	**0.0849**	**2.9895**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,639.4091	IE	IE	0.0849	2.9895
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-841.9941**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-841.9941	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	312.2813	0.4727	0.0033	0.1175	4.1360
Grassland converted to other Land-Use Categories	NO	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	**862.8879**	**0.4854**	**0.0033**	**0.1206**	**4.2477**
A. Forest Land	**-14,192.6313**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-14,192.6313	NE,NO	NE,NO	NO	NO
B. Cropland	**15,630.7893**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	862.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,095.8527	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,613.5044**	**0.1396**	**0.0010**	**0.0347**	**1.2211**
1. Grassland remaining Grassland	484.0766	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,695.4044	0.1396	0.0010	0.0347	1.2211
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,671.0104**	**0.3459**	**0.0024**	**0.0859**	**3.0266**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,591.7428	IE	IE	0.0859	3.0266
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-632.7762**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-632.7762	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	321.3855	0.4854	0.0033	0.1206	4.2477
Grassland converted to other Land-Use Categories	NO	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	**991.7755**	**0.4492**	**0.0031**	**0.1116**	**3.9305**
A. Forest Land	**-13,948.2066**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,948.2066	NE,NO	NE,NO	NO	NO
B. Cropland	**15,770.7207**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	826.2752	NA	NA	NO	NO
2. Land converted to Cropland	14,112.9956	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,540.8636**	**0.1553**	**0.0011**	**0.0386**	**1.3586**
1. Grassland remaining Grassland	558.0091	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,796.8607	0.1553	0.0011	0.0386	1.3586
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,609.9995**	**0.2939**	**0.0020**	**0.0730**	**2.5718**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,542.6419	IE	IE	0.0730	2.5718
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-899.8745**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-899.8745	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	318.9174	0.4492	0.0031	0.1116	3.9305
Grassland converted to other Land-Use Categories	NO	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	**850.2203**	**0.5209**	**0.0036**	**0.1294**	**4.5576**
A. Forest Land	**-13,720.0644**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,720.0644	NE,NO	NE,NO	NO	NO
B. Cropland	**15,802.5263**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	789.6086	NA	NA	NO	NO
2. Land converted to Cropland	14,130.5483	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,789.1191**	**0.1829**	**0.0013**	**0.0454**	**1.6000**
1. Grassland remaining Grassland	475.2946	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-7,897.2063	0.1829	0.0013	0.0454	1.6000
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,577.9680**	**0.3380**	**0.0023**	**0.0840**	**2.9575**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,500.5089	IE	IE	0.0840	2.9575
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,021.0904**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,021.0904	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	340.8608	0.5209	0.0036	0.1294	4.5576
Grassland converted to other Land-Use Categories	NO	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	**501.5962**	**0.5444**	**0.0037**	**0.1353**	**4.7636**
A. Forest Land	**-13,511.5946**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,511.5946	NE,NO	NE,NO	NO	NO
B. Cropland	**15,543.0266**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	752.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,148.4050	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-6,892.8363**	**0.1517**	**0.0010**	**0.0377**	**1.3277**
1. Grassland remaining Grassland	419.9474	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,017.4819	0.1517	0.0010	0.0377	1.3277
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,559.9221**	**0.3927**	**0.0027**	**0.0976**	**3.4359**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,469.9355	IE	IE	0.0976	3.4359
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,196.9216**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,196.9216	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	351.4755	0.5444	0.0037	0.1353	4.7636
Grassland converted to other Land-Use Categories	NO	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	**-53.0908**	**0.5448**	**0.0037**	**0.1354**	**4.7670**
A. Forest Land	**-13,406.2144**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,406.2144	NE,NO	NE,NO	NO	NO
B. Cropland	**15,428.3246**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	716.2752	NA	NA	NO	NO
2. Land converted to Cropland	14,166.4714	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,290.8038**	**0.1585**	**0.0011**	**0.0394**	**1.3867**
1. Grassland remaining Grassland	314.5630	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,117.8348	0.1585	0.0011	0.0394	1.3867
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,521.4715**	**0.3863**	**0.0027**	**0.0960**	**3.3803**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,432.9406	IE	IE	0.0960	3.3803
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,305.8687**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,305.8687	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	356.4993	0.5448	0.0037	0.1354	4.7670
Grassland converted to other Land-Use Categories	NO	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	**-267.4823**	**0.7751**	**0.0053**	**0.1926**	**6.7820**
A. Forest Land	**-13,504.3701**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,504.3701	NE,NO	NE,NO	NO	NO
B. Cropland	**15,329.2460**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	679.6086	NA	NA	NO	NO
2. Land converted to Cropland	14,184.6639	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,282.6358**	**0.3922**	**0.0027**	**0.0975**	**3.4320**
1. Grassland remaining Grassland	431.5887	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,136.1810	0.3922	0.0027	0.0975	3.4320
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,458.2846**	**0.3829**	**0.0026**	**0.0951**	**3.3500**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,370.5476	IE	IE	0.0951	3.3500
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-1,268.0070**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-1,268.0070	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	413.9422	0.7751	0.0053	0.1926	6.7820
Grassland converted to other Land-Use Categories	NO	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	**-449.0135**	**0.9777**	**0.0067**	**0.2430**	**8.5553**
A. Forest Land	**-13,804.8838**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-13,804.8838	NE,NO	NE,NO	NO	NO
B. Cropland	**15,339.0471**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	642.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,203.2373	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,445.6025**	**0.5885**	**0.0040**	**0.1462**	**5.1498**
1. Grassland remaining Grassland	427.0955	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,174.0082	0.5885	0.0040	0.1462	5.1498
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,412.5089**	**0.3892**	**0.0027**	**0.0967**	**3.4055**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,323.3162	IE	IE	0.0967	3.4055
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-950.0832**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-950.0832	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	464.8177	0.9777	0.0067	0.2430	8.5553
Grassland converted to other Land-Use Categories	NO	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	**-602.5357**	**1.1740**	**0.0081**	**0.2917**	**10.2729**
A. Forest Land	**-14,347.9995**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-14,347.9995	NE,NO	NE,NO	NO	NO
B. Cropland	**15,286.5077**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	620.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,221.7451	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,469.6647**	**0.7748**	**0.0053**	**0.1925**	**6.7798**
1. Grassland remaining Grassland	465.8999	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,216.2479	0.7748	0.0053	0.1925	6.7798
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,373.8510**	**0.3992**	**0.0027**	**0.0992**	**3.4931**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,282.3646	IE	IE	0.0992	3.4931
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**-445.2302**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	-445.2302	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	513.9973	1.1740	0.0081	0.2917	10.2729
Grassland converted to other Land-Use Categories	NO	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	**-1,124.4246**	**1.0061**	**0.0069**	**0.2500**	**8.8031**
A. Forest Land	**-15,045.1597**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-15,045.1597	NE,NO	NE,NO	NO	NO
B. Cropland	**15,312.5270**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	598.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,240.1364	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,765.9316**	**0.6733**	**0.0046**	**0.1673**	**5.8910**
1. Grassland remaining Grassland	298.2243	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,329.5332	0.6733	0.0046	0.1673	5.8910
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,326.7214**	**0.3328**	**0.0023**	**0.0827**	**2.9121**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,250.4533	IE	IE	0.0827	2.9121
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**47.4184**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	47.4184	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	479.4723	1.0061	0.0069	0.2500	8.8031
Grassland converted to other Land-Use Categories	NO	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	**-1,180.7986**	**0.9721**	**0.0067**	**0.2415**	**8.5058**
A. Forest Land	**-15,645.8081**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-15,645.8081	NE,NO	NE,NO	NO	NO
B. Cropland	**15,384.4810**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	576.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,258.3669	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,558.9674**	**0.6343**	**0.0044**	**0.1576**	**5.5499**
1. Grassland remaining Grassland	503.4788	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,430.9600	0.6343	0.0044	0.1576	5.5499
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,302.2194**	**0.3378**	**0.0023**	**0.0839**	**2.9558**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,224.8044	IE	IE	0.0839	2.9558
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**337.2765**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	337.2765	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	475.4468	0.9721	0.0067	0.2415	8.5058
Grassland converted to other Land-Use Categories	NO	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	**-1,934.5225**	**0.9326**	**0.0064**	**0.2317**	**8.1604**
A. Forest Land	**-16,302.0335**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-16,302.0335	NE,NO	NE,NO	NO	NO
B. Cropland	**15,315.7435**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	554.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,276.3979	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,857.6200**	**0.5657**	**0.0039**	**0.1406**	**4.9499**
1. Grassland remaining Grassland	354.7969	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,542.8932	0.5657	0.0039	0.1406	4.9499
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,290.5651**	**0.3669**	**0.0025**	**0.0912**	**3.2105**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,206.4807	IE	IE	0.0912	3.2105
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**618.8224**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	618.8224	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	469.9644	0.9326	0.0064	0.2317	8.1604
Grassland converted to other Land-Use Categories	NO	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	**-2,056.1185**	**0.9250**	**0.0064**	**0.2298**	**8.0934**
A. Forest Land	**-15,737.9972**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Forest Land remaining Forest Land	NE,NO	NE,NO	NE,NO	NO	NO
2. Land converted to Forest Land	-15,737.9972	NE,NO	NE,NO	NO	NO
B. Cropland	**15,258.3278**	**NA,NE,NO**	**NA,NE,NO**	**NO**	**NO**
1. Cropland remaining Cropland	532.9419	NA	NA	NO	NO
2. Land converted to Cropland	14,294.1958	NE,NO	NA,NE,NO	NO	NO
C. Grassland	**-7,934.2927**	**0.5699**	**0.0039**	**0.1416**	**4.9867**
1. Grassland remaining Grassland	404.4256	NE,NO	NE,NO	NO	NO
2. Land converted to Grassland	-8,626.7522	0.5699	0.0039	0.1416	4.9867
D. Wetlands	**IE,NE,NO**	**NE,NO**	**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	NE,NO	NE,NO	NO	NO
E. Settlements	**6,261.5633**	**0.3551**	**0.0024**	**0.0882**	**3.1067**
1. Settlements remaining Settlements	NO	NO	NO	NO	NO
2. Land converted to Settlements	6,180.1977	IE	IE	0.0882	3.1067
F. Other Land	**NA,NE,NO**	**NE,NO**	**NE,NO**	**NO**	**NO**
1. Other Land remaining Other Land		NO	NO	NO	NO
2. Land converted to Other Land	NO	NO	NO	NO	NO
G. Other *(please specify)*	**96.2803**	**NE**	**NE**	**NE**	**NE**
Harvested Wood Products	96.2803	NE	NE	NE	NE
Information items					
Forest Land converted to other Land-Use Categories	471.5872	0.9250	0.0064	0.2298	8.0934
Grassland converted to other Land-Use Categories	NO	NO	NO	NO	NO

24.3 Appendix 3: Sectoral Tables for Land Use Change and Forestry 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
5	**Total Land-Use Categories**	**Gg CO2**	**2,881.6**	**2,754.5**	**2,250.8**	**1,068.2**	**862.9**	**991.8**	**850.2**	**501.6**	**-53.1**	**-267.5**	**-449.0**	**-602.5**	**-1,124.4**	**-1,180.8**	**-1,934.5**	**-2,056.1**
5A	Forest Land	Gg CO2	-12,202.6	-12,714.6	-13,340.1	-13,714.1	-14,192.6	-13,948.2	-13,720.1	-13,511.6	-13,406.2	-13,504.4	-13,804.9	-14,348.0	-15,045.2	-15,645.8	-16,302.0	-15,738.0
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	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5A2	Land converted to Forest-Land	Gg CO2	-12,202.6	-12,714.6	-13,340.1	-13,714.1	-14,192.6	-13,948.2	-13,720.1	-13,511.6	-13,406.2	-13,504.4	-13,804.9	-14,348.0	-15,045.2	-15,645.8	-16,302.0	-15,738.0
5B	**Cropland**	**Gg CO2**	**15,836.0**	**15,995.5**	**16,001.1**	**15,577.2**	**15,630.8**	**15,770.7**	**15,802.5**	**15,543.0**	**15,428.3**	**15,329.2**	**15,339.0**	**15,286.5**	**15,312.5**	**15,384.5**	**15,315.7**	**15,258.3**
5B1	Cropland remaining Cropland	Gg CO2	1,009.6	972.9	936.3	899.6	862.9	826.3	789.6	752.9	716.3	679.6	642.9	620.9	598.9	576.9	554.9	532.9
5B2	Land converted to Cropland	Gg CO2	14,034.0	14,048.1	14,063.3	14,079.2	14,095.9	14,113.0	14,130.5	14,148.4	14,166.5	14,184.7	14,203.2	14,221.7	14,240.1	14,258.4	14,276.4	14,294.2
5B (liming)	*Liming of Cropland*	*Gg CO2*	*792.5*	*974.4*	*1,001.5*	*598.4*	*672.0*	*831.4*	*882.4*	*641.7*	*545.6*	*465.0*	*492.9*	*443.8*	*473.4*	*549.2*	*484.4*	*431.2*
5C	**Grassland**	**Gg CO2**	**-6,200.2**	**-6,151.9**	**-6,260.5**	**-6,670.6**	**-6,613.5**	**-6,540.9**	**-6,789.1**	**-6,892.8**	**-7,290.8**	**-7,282.6**	**-7,445.6**	**-7,469.7**	**-7,765.9**	**-7,559.0**	**-7,857.6**	**-7,934.3**
5C1	Grassland remaining Grassland	Gg CO2	389.5	396.3	389.7	382.6	484.1	558.0	475.3	419.9	314.6	431.6	427.1	465.9	298.2	503.5	354.8	404.4
5C2	Land converted to Grassland	Gg CO2	-7,227.8	-7,345.7	-7,458.3	-7,585.2	-7,695.4	-7,796.9	-7,897.2	-8,017.5	-8,117.8	-8,136.2	-8,174.0	-8,216.2	-8,329.5	-8,431.0	-8,542.9	-8,626.8
5C (liming)	*Liming of Grassland*	*Gg CO2*	*638.0*	*797.5*	*808.0*	*531.9*	*597.8*	*698.0*	*632.8*	*704.7*	*512.5*	*422.0*	*301.3*	*280.7*	*265.4*	*368.5*	*330.5*	*288.0*
5D	**Wetland**	**Gg CO2**	**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
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**6,904.2**	**6,835.8**	**6,770.0**	**6,717.7**	**6,671.0**	**6,610.0**	**6,578.0**	**6,559.9**	**6,521.5**	**6,458.3**	**6,412.5**	**6,373.9**	**6,326.7**	**6,302.2**	**6,290.6**	**6,261.6**
5E1	Settlements remaining Settlements	Gg CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	6,802.1	6,743.6	6,687.5	6,639.4	6,591.7	6,542.6	6,500.5	6,469.9	6,432.9	6,370.5	6,323.3	6,282.4	6,250.5	6,224.8	6,206.5	6,180.2
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	*102.1*	*92.2*	*82.5*	*78.3*	*79.3*	*67.4*	*77.5*	*90.0*	*88.5*	*87.7*	*89.2*	*91.5*	*76.3*	*77.4*	*84.1*	*81.4*
5F	**Other-Land**	**Gg CO2**	**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
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-1,455.9**	**-1,210.2**	**-919.6**	**-842.0**	**-632.8**	**-899.9**	**-1,021.1**	**-1,196.9**	**-1,305.9**	**-1,268.0**	**-950.1**	**-445.2**	**47.4**	**337.3**	**618.8**	**96.3**
5G1	Harvested Wood Products	Gg CO2	-1,455.9	-1,210.2	-919.6	-842.0	-632.8	-899.9	-1,021.1	-1,196.9	-1,305.9	-1,268.0	-950.1	-445.2	47.4	337.3	618.8	96.3
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	318.8	318.5	319.1	312.3	321.4	318.9	340.9	351.5	356.5	413.9	464.8	514.0	479.5	475.4	470.0	471.6
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

UK			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total 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**	**0.978**	**1.174**	**1.006**	**0.972**	**0.933**	**0.925**
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
5E	Settlements	Gg CH4	0.445	0.402	0.360	0.342	0.346	0.294	0.338	0.393	0.386	0.383	0.389	0.399	0.333	0.338	0.367	0.355
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	0.978	1.174	1.006	0.972	0.933	0.925
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
5	**Total Land-Use Categories**	**Gg N2O**	**0.004**	**0.004**	**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**
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
5E	Settlements	Gg N2O	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.003	0.002
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.004	0.004	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
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
5	**Total 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**	**0.243**	**0.292**	**0.250**	**0.242**	**0.232**	**0.230**
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
5E	Settlements	Gg NOx	0.111	0.100	0.089	0.085	0.086	0.073	0.084	0.098	0.096	0.095	0.097	0.099	0.083	0.084	0.091	0.088
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	0.243	0.292	0.250	0.242	0.232	0.230
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
5	**Total 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**	**8.555**	**10.273**	**8.803**	**8.506**	**8.160**	**8.093**
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
5E	Settlements	Gg CO	3.897	3.520	3.150	2.990	3.027	2.572	2.958	3.436	3.380	3.350	3.406	3.493	2.912	2.956	3.210	3.107
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	8.555	10.273	8.803	8.506	8.160	8.093
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

Table A3. 2 : England

England			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total Land-Use Categories**	**Gg CO2**	**5,711.5**	**5,817.9**	**5,644.5**	**4,996.1**	**4,993.5**	**5,081.0**	**4,891.2**	**4,551.6**	**4,162.6**	**3,990.5**	**3,907.8**	**3,841.6**	**3,552.3**	**3,562.9**	**3,258.6**	**3,079.2**
5A	Forest Land	Gg CO2	-2,733.0	-2,775.4	-2,855.7	-2,850.9	-2,889.0	-2,825.1	-2,893.9	-2,871.5	-2,817.9	-2,874.0	-2,759.6	-2,945.8	-3,169.1	-3,333.1	-3,540.4	-3,447.6
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	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5A2	Land converted to Forest-Land	Gg CO2	-2,733.0	-2,775.4	-2,855.7	-2,850.9	-2,889.0	-2,825.1	-2,893.9	-2,871.5	-2,817.9	-2,874.0	-2,759.6	-2,945.8	-3,169.1	-3,333.1	-3,540.4	-3,447.6
5B	**Cropland**	**Gg CO2**	**7,507.7**	**7,595.4**	**7,559.6**	**7,177.0**	**7,182.8**	**7,257.8**	**7,247.4**	**7,003.1**	**6,877.2**	**6,763.8**	**6,741.7**	**6,657.9**	**6,662.1**	**6,694.5**	**6,614.8**	**6,545.4**
5B1	Cropland remaining Cropland	Gg CO2	1,124.7	1,088.0	1,051.3	1,014.7	978.0	941.3	904.7	868.0	831.3	794.7	758.0	736.0	714.0	692.0	670.0	648.0
5B2	Land converted to Cropland	Gg CO2	5,745.5	5,722.1	5,700.7	5,681.2	5,663.4	5,647.2	5,632.4	5,619.0	5,606.7	5,595.6	5,585.8	5,576.9	5,568.8	5,561.5	5,554.8	5,548.8
5B (liming)	*Liming of Cropland*	*Gg CO2*	*637.6*	*785.3*	*807.5*	*481.1*	*541.4*	*669.2*	*710.2*	*516.1*	*439.1*	*373.6*	*397.9*	*345.0*	*379.3*	*441.0*	*389.9*	*348.6*
5C	**Grassland**	**Gg CO2**	**-2,596.7**	**-2,554.3**	**-2,635.7**	**-2,856.0**	**-2,820.0**	**-2,778.9**	**-2,917.5**	**-2,965.1**	**-3,176.8**	**-3,160.0**	**-3,218.6**	**-3,162.9**	**-3,372.8**	**-3,312.1**	**-3,436.6**	**-3,511.1**
5C1	Grassland remaining Grassland	Gg CO2	228.1	245.5	220.4	218.5	280.8	322.3	268.2	250.6	191.2	250.0	256.9	298.0	174.8	250.6	184.2	189.3
5C2	Land converted to Grassland	Gg CO2	-3,170.1	-3,231.2	-3,288.7	-3,356.8	-3,413.1	-3,463.5	-3,513.2	-3,577.6	-3,627.9	-3,619.5	-3,625.2	-3,634.4	-3,694.8	-3,746.8	-3,806.7	-3,846.6
5C (liming)	*Liming of Grassland*	*Gg CO2*	*345.3*	*431.4*	*432.6*	*282.3*	*312.3*	*362.3*	*327.6*	*361.9*	*260.0*	*209.5*	*149.7*	*173.5*	*147.2*	*184.1*	*185.9*	*146.2*
5D	**Wetland**	**Gg CO2**	**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
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**3,894.9**	**3,837.5**	**3,782.5**	**3,737.5**	**3,696.8**	**3,646.2**	**3,616.7**	**3,597.6**	**3,564.0**	**3,513.0**	**3,474.8**	**3,441.9**	**3,403.2**	**3,380.9**	**3,368.1**	**3,343.0**
5E1	Settlements remaining Settlements	Gg CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	3,821.6	3,771.3	3,723.2	3,681.2	3,639.9	3,597.8	3,561.1	3,532.9	3,500.5	3,450.0	3,410.7	3,376.2	3,348.4	3,325.3	3,307.7	3,284.6
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	*73.3*	*66.2*	*59.2*	*56.2*	*56.9*	*48.4*	*55.6*	*64.6*	*63.6*	*63.0*	*64.1*	*65.7*	*54.8*	*55.6*	*60.4*	*58.4*
5F	**Other-Land**	**Gg CO2**	**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
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-361.3**	**-285.3**	**-206.2**	**-211.4**	**-177.2**	**-219.1**	**-161.5**	**-212.4**	**-284.0**	**-252.3**	**-330.5**	**-149.5**	**28.9**	**132.7**	**252.6**	**149.5**
5G1	Harvested Wood Products	Gg CO2	-361.3	-285.3	-206.2	-211.4	-177.2	-219.1	-161.5	-212.4	-284.0	-252.3	-330.5	-149.5	28.9	132.7	252.6	149.5
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	150.0	154.2	158.7	157.6	167.8	169.4	188.3	199.0	205.4	249.3	288.4	326.0	303.5	302.7	300.8	303.8
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

England			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total 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**	**0.702**	**0.843**	**0.723**	**0.698**	**0.670**	**0.664**
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
5E	Settlements	Gg CH4	0.320	0.289	0.259	0.245	0.248	0.211	0.243	0.282	0.277	0.275	0.280	0.287	0.239	0.243	0.264	0.255
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	0.702	0.843	0.723	0.698	0.670	0.664
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
5	**Total Land-Use Categories**	**Gg N2O**	**0.003**	**0.003**	**0.003**	**0.002**	**0.002**	**0.002**	**0.003**	**0.003**	**0.003**	**0.004**	**0.005**	**0.006**	**0.005**	**0.005**	**0.005**	**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	0.002	0.003	0.004	0.003	0.003	0.003	0.003
5E	Settlements	Gg N2O	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.005	0.006	0.005	0.005	0.005	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
5	**Total 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**	**0.174**	**0.210**	**0.180**	**0.173**	**0.166**	**0.165**
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
5E	Settlements	Gg NOx	0.079	0.072	0.064	0.061	0.062	0.052	0.060	0.070	0.069	0.068	0.069	0.071	0.059	0.060	0.065	0.063
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	0.174	0.210	0.180	0.173	0.166	0.165
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
5	**Total 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**	**6.144**	**7.378**	**6.322**	**6.109**	**5.861**	**5.813**
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
5E	Settlements	Gg CO	2.799	2.528	2.262	2.147	2.174	1.847	2.124	2.468	2.428	2.406	2.446	2.509	2.091	2.123	2.306	2.231
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	6.144	7.378	6.322	6.109	5.861	5.813
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

Table A3. 3 : Scotland

Scotland			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total Land-Use Categories**	**Gg CO2**	**-2,541.0**	**-2,812.8**	**-3,109.7**	**-3,541.5**	**-3,730.4**	**-3,720.5**	**-3,680.9**	**-3,726.7**	**-3,866.7**	**-3,937.2**	**-3,944.4**	**-4,016.6**	**-4,194.7**	**-4,243.7**	**-4,649.0**	**-4,581.0**
5A	Forest Land	Gg CO2	-7,547.4	-7,951.4	-8,364.7	-8,714.0	-9,062.0	-8,973.0	-8,860.1	-8,837.0	-8,878.0	-9,075.3	-8,869.0	-9,163.7	-9,610.8	-10,053.5	-10,472.5	-10,132.7
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	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5A2	Land converted to Forest-Land	Gg CO2	-7,547.4	-7,951.4	-8,364.7	-8,714.0	-9,062.0	-8,973.0	-8,860.1	-8,837.0	-8,878.0	-9,075.3	-8,869.0	-9,163.7	-9,610.8	-10,053.5	-10,472.5	-10,132.7
5B	**Cropland**	**Gg CO2**	**6,104.1**	**6,178.0**	**6,224.7**	**6,198.5**	**6,249.9**	**6,316.1**	**6,361.7**	**6,356.5**	**6,373.8**	**6,393.0**	**6,427.4**	**6,462.4**	**6,485.6**	**6,524.8**	**6,539.1**	**6,554.1**
5B1	Cropland remaining Cropland	Gg CO2	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9	-78.9
5B2	Land converted to Cropland	Gg CO2	6,048.6	6,093.0	6,135.7	6,176.9	6,216.4	6,254.4	6,291.0	6,326.1	6,359.8	6,392.3	6,423.3	6,453.2	6,481.8	6,509.3	6,535.7	6,561.1
5B (liming)	*Liming of Cropland*	*Gg CO2*	*134.5*	*163.9*	*167.8*	*100.6*	*112.4*	*140.6*	*149.7*	*109.4*	*92.8*	*79.6*	*83.0*	*88.1*	*82.7*	*94.4*	*82.2*	*71.9*
5C	**Grassland**	**Gg CO2**	**-2,119.5**	**-2,131.7**	**-2,142.6**	**-2,245.0**	**-2,221.7**	**-2,197.8**	**-2,274.0**	**-2,331.3**	**-2,450.9**	**-2,424.8**	**-2,483.0**	**-2,558.7**	**-2,615.5**	**-2,473.5**	**-2,629.3**	**-2,596.4**
5C1	Grassland remaining Grassland	Gg CO2	59.9	49.2	67.8	62.6	101.7	134.2	105.6	67.8	21.9	80.1	68.6	66.4	21.9	151.3	69.0	113.6
5C2	Land converted to Grassland	Gg CO2	-2,313.2	-2,348.8	-2,383.4	-2,421.3	-2,455.7	-2,488.3	-2,520.7	-2,557.8	-2,590.5	-2,604.9	-2,623.9	-2,643.9	-2,680.1	-2,713.6	-2,749.6	-2,779.4
5C (liming)	*Liming of Grassland*	*Gg CO2*	*133.8*	*167.8*	*172.9*	*113.8*	*132.4*	*156.3*	*141.1*	*158.7*	*117.8*	*100.0*	*72.3*	*18.9*	*42.7*	*88.7*	*51.3*	*69.5*
5D	**Wetland**	**Gg CO2**	**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
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**1,736.0**	**1,727.5**	**1,719.3**	**1,713.7**	**1,709.0**	**1,700.8**	**1,698.8**	**1,699.6**	**1,695.6**	**1,685.8**	**1,679.5**	**1,674.7**	**1,667.8**	**1,665.7**	**1,666.4**	**1,663.0**
5E1	Settlements remaining Settlements	Gg CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	1,713.0	1,706.8	1,700.7	1,696.1	1,691.2	1,685.6	1,681.3	1,679.4	1,675.7	1,666.0	1,659.5	1,654.1	1,650.6	1,648.3	1,647.5	1,644.7
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	*23.0*	*20.7*	*18.6*	*17.6*	*17.8*	*15.2*	*17.4*	*20.2*	*19.9*	*19.7*	*20.1*	*20.6*	*17.2*	*17.4*	*18.9*	*18.3*
5F	**Other-Land**	**Gg CO2**	**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
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-714.2**	**-635.1**	**-546.4**	**-494.7**	**-405.6**	**-566.5**	**-607.3**	**-614.5**	**-607.1**	**-515.8**	**-699.4**	**-431.3**	**-121.6**	**92.8**	**247.3**	**-69.0**
5G1	Harvested Wood Products	Gg CO2	-714.2	-635.1	-546.4	-494.7	-405.6	-566.5	-607.3	-614.5	-607.1	-515.8	-699.4	-431.3	-121.6	92.8	247.3	-69.0
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	87.9	86.9	86.3	84.0	85.3	84.1	88.4	90.2	90.7	103.1	114.1	124.7	116.4	115.1	113.5	113.5
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Scotland			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total 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**	**0.220**	**0.264**	**0.226**	**0.219**	**0.210**	**0.208**
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
5E	Settlements	Gg CH4	0.100	0.091	0.081	0.077	0.078	0.066	0.076	0.088	0.087	0.086	0.088	0.090	0.075	0.076	0.083	0.080
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	0.220	0.264	0.226	0.219	0.210	0.208
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
5	**Total Land-Use Categories**	**Gg N2O**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.002**	**0.002**	**0.002**	**0.002**	**0.001**	**0.001**
5C2	Land converted to Grassland	Gg N2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001
5E	Settlements	Gg N2O	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Information Item	Forest Land converted to other Land-Use Categories	Gg N2O	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001
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
5	**Total 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**	**0.066**	**0.056**	**0.054**	**0.052**	**0.052**
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
5E	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	0.022	0.019	0.019	0.021	0.020
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	0.066	0.056	0.054	0.052	0.052
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
5	**Total 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**	**1.925**	**2.311**	**1.981**	**1.914**	**1.836**	**1.821**
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
5E	Settlements	Gg CO	0.877	0.792	0.709	0.673	0.681	0.579	0.665	0.773	0.761	0.754	0.766	0.786	0.655	0.665	0.722	0.699
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	1.925	2.311	1.981	1.914	1.836	1.821
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

Table A3. 4 : Wales

Wales			**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
5	**Total Land-Use Categories**	**Gg CO2**	**-243.8**	**-203.6**	**-205.7**	**-260.0**	**-261.0**	**-222.9**	**-183.1**	**-131.2**	**-123.7**	**-72.2**	**-134.1**	**-137.6**	**-174.3**	**-203.9**	**-243.8**	**-246.6**
5A	Forest Land	Gg CO2	-1,178.2	-1,245.9	-1,358.4	-1,431.5	-1,491.4	-1,427.4	-1,247.3	-1,082.5	-1,001.2	-837.5	-1,440.7	-1,476.8	-1,521.6	-1,558.8	-1,583.9	-1,509.5
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	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5A2	Land converted to Forest-Land	Gg CO2	-1,178.2	-1,245.9	-1,358.4	-1,431.5	-1,491.4	-1,427.4	-1,247.3	-1,082.5	-1,001.2	-837.5	-1,440.7	-1,476.8	-1,521.6	-1,558.8	-1,583.9	-1,509.5
5B	**Cropland**	**Gg CO2**	**969.2**	**978.1**	**984.9**	**986.0**	**992.9**	**1,000.5**	**1,006.5**	**1,008.5**	**1,012.0**	**1,015.9**	**1,020.7**	**1,024.5**	**1,029.4**	**1,034.8**	**1,038.1**	**1,041.0**
5B1	Cropland remaining Cropland	Gg CO2	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1	-11.1
5B2	Land converted to Cropland	Gg CO2	969.3	975.9	982.2	988.3	994.2	999.9	1,005.3	1,010.5	1,015.6	1,020.4	1,025.1	1,029.7	1,034.1	1,038.2	1,042.3	1,046.1
5B (liming)	*Liming of Cropland*	*Gg CO2*	*11.0*	*13.3*	*13.8*	*8.7*	*9.8*	*11.7*	*12.2*	*9.0*	*7.5*	*6.5*	*6.6*	*5.8*	*6.4*	*7.6*	*6.9*	*6.0*
5C	**Grassland**	**Gg CO2**	**-403.2**	**-393.3**	**-401.3**	**-450.7**	**-452.1**	**-448.4**	**-466.2**	**-465.7**	**-502.1**	**-518.7**	**-543.1**	**-544.6**	**-561.8**	**-558.6**	**-569.8**	**-588.4**
5C1	Grassland remaining Grassland	Gg CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	-490.8	-502.4	-513.6	-525.4	-536.1	-546.2	-556.1	-566.9	-576.5	-581.3	-587.1	-593.0	-602.8	-611.9	-621.4	-629.2
5C (liming)	*Liming of Grassland*	*Gg CO2*	*87.6*	*109.1*	*112.3*	*74.7*	*84.1*	*97.8*	*89.9*	*101.2*	*74.4*	*62.6*	*44.0*	*48.4*	*41.0*	*53.3*	*51.5*	*40.8*
5D	**Wetland**	**Gg CO2**	**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
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**703.8**	**701.5**	**699.3**	**697.8**	**696.6**	**694.5**	**694.1**	**694.3**	**693.4**	**691.1**	**689.7**	**688.7**	**687.1**	**686.8**	**687.2**	**686.6**
5E1	Settlements remaining Settlements	Gg CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	698.0	696.3	694.6	693.3	692.1	690.7	689.7	689.2	688.4	686.1	684.6	683.5	682.8	682.4	682.4	682.0
5E (Biomass burning)	*Forest Land converted to Settlement*	*Gg CO2*	*5.8*	*5.2*	*4.7*	*4.4*	*4.5*	*3.8*	*4.4*	*5.1*	*5.0*	*5.0*	*5.1*	*5.2*	*4.3*	*4.4*	*4.8*	*4.6*
5F	**Other-Land**	**Gg CO2**	**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
5F2	Land converted to Other-Land	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5G	**Other activities**	**Gg CO2**	**-335.5**	**-243.9**	**-130.2**	**-61.6**	**-7.1**	**-42.0**	**-170.2**	**-285.8**	**-325.8**	**-423.0**	**139.3**	**170.6**	**192.6**	**191.8**	**184.6**	**123.6**
5G1	Harvested Wood Products	Gg CO2	-335.5	-243.9	-130.2	-61.6	-7.1	-42.0	-170.2	-285.8	-325.8	-423.0	139.3	170.6	192.6	191.8	184.6	123.6
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	18.0	17.9	18.0	17.6	18.1	18.0	19.2	19.8	20.1	23.4	26.3	29.1	27.1	26.9	26.6	26.7
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Wales			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total 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**	**0.067**	**0.057**	**0.055**	**0.053**	**0.053**
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
5E	Settlements	Gg CH4	0.025	0.023	0.020	0.019	0.020	0.017	0.019	0.022	0.022	0.022	0.022	0.023	0.019	0.019	0.021	0.020
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	0.067	0.057	0.055	0.053	0.053
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
5	**Total Land-Use Categories**	**Gg N2O**	**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**
5C2	Land converted to Grassland	Gg N2O	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
5E	Settlements	Gg N2O	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 N2O	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 N2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total 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**	**0.014**	**0.014**	**0.013**	**0.013**
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
5E	Settlements	Gg NOx	0.006	0.006	0.005	0.005	0.005	0.004	0.005	0.006	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005
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	0.014	0.014	0.013	0.013
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
5	**Total 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**	**0.486**	**0.584**	**0.500**	**0.483**	**0.464**	**0.460**
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
5E	Settlements	Gg CO	0.221	0.200	0.179	0.170	0.172	0.146	0.168	0.195	0.192	0.190	0.193	0.198	0.165	0.168	0.182	0.176
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	0.486	0.584	0.500	0.483	0.464	0.460
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

Table A3. 5 : N. Ireland

Northern Ireland			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total Land-Use Categories**	**Gg CO2**	**-45.2**	**-47.0**	**-78.2**	**-126.4**	**-139.2**	**-145.8**	**-177.0**	**-192.1**	**-225.3**	**-248.5**	**-278.4**	**-289.9**	**-307.8**	**-296.0**	**-300.2**	**-307.7**
5A	Forest Land	Gg CO2	-743.9	-741.8	-761.4	-717.6	-750.1	-722.7	-718.8	-720.6	-709.1	-717.6	-735.6	-761.7	-743.6	-700.3	-705.2	-648.2
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	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5A2	Land converted to Forest-Land	Gg CO2	-743.9	-741.8	-761.4	-717.6	-750.1	-722.7	-718.8	-720.6	-709.1	-717.6	-735.6	-761.7	-743.6	-700.3	-705.2	-648.2
5B	**Cropland**	**Gg CO2**	**1,255.0**	**1,244.1**	**1,232.0**	**1,215.8**	**1,205.1**	**1,196.4**	**1,187.0**	**1,174.9**	**1,165.3**	**1,156.6**	**1,149.3**	**1,141.8**	**1,135.5**	**1,130.4**	**1,123.8**	**1,117.8**
5B1	Cropland remaining Cropland	Gg CO2	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1	-25.1
5B2	Land converted to Cropland	Gg CO2	1,270.7	1,257.2	1,244.6	1,232.8	1,221.8	1,211.5	1,201.8	1,192.8	1,184.3	1,176.4	1,169.0	1,162.0	1,155.5	1,149.3	1,143.6	1,138.2
5B (liming)	*Liming of Cropland*	*Gg CO2*	*9.4*	*12.0*	*12.4*	*8.0*	*8.4*	*10.0*	*10.2*	*7.2*	*6.1*	*5.3*	*5.4*	*4.9*	*5.1*	*6.1*	*5.4*	*4.7*
5C	**Grassland**	**Gg CO2**	**-1,080.9**	**-1,072.6**	**-1,080.9**	**-1,119.0**	**-1,119.8**	**-1,115.8**	**-1,131.5**	**-1,130.7**	**-1,161.1**	**-1,179.1**	**-1,200.9**	**-1,203.5**	**-1,215.8**	**-1,214.7**	**-1,221.9**	**-1,238.4**
5C1	Grassland remaining Grassland	Gg CO2	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5	101.5
5C2	Land converted to Grassland	Gg CO2	-1,253.7	-1,263.3	-1,272.6	-1,281.7	-1,290.4	-1,298.9	-1,307.1	-1,315.1	-1,322.9	-1,330.4	-1,337.8	-1,344.9	-1,351.9	-1,358.6	-1,365.2	-1,371.6
5C (liming)	*Liming of Grassland*	*Gg CO2*	*71.3*	*89.2*	*90.2*	*61.1*	*69.0*	*81.6*	*74.1*	*82.9*	*60.3*	*49.8*	*35.3*	*39.9*	*34.5*	*42.4*	*41.7*	*31.6*
5D	**Wetland**	**Gg CO2**	**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
5D2	Land converted to Wetland	Gg CO2	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
5E	**Settlements**	**Gg CO2**	**569.5**	**569.2**	**568.9**	**568.7**	**568.6**	**568.5**	**568.4**	**568.4**	**568.4**	**568.4**	**568.5**	**568.6**	**568.6**	**568.7**	**568.9**	**569.0**
5E1	Settlements remaining Settlements	Gg CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	569.5	569.2	568.9	568.7	568.6	568.5	568.4	568.4	568.4	568.4	568.5	568.6	568.6	568.7	568.9	569.0
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*	*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**
5F1	Other-Land remaining Other-land	Gg CO2	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
5G	**Other activities**	**Gg CO2**	**-44.9**	**-45.8**	**-36.8**	**-74.3**	**-42.9**	**-72.2**	**-82.1**	**-84.2**	**-88.9**	**-76.9**	**-59.6**	**-35.0**	**-52.5**	**-80.1**	**-65.8**	**-107.8**
5G1	Harvested Wood Products	Gg CO2	-44.9	-45.8	-36.8	-74.3	-42.9	-72.2	-82.1	-84.2	-88.9	-76.9	-59.6	-35.0	-52.5	-80.1	-65.8	-107.8
Information Item	Forest Land converted to other Land-Use Categories	Gg CO2	62.9	59.4	56.2	53.1	50.2	47.5	44.9	42.5	40.2	38.1	36.1	34.2	32.4	30.7	29.1	27.6
Information Item	Grassland converted to other Land-Use Categories	Gg CO2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Northern Ireland			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
5	**Total Land-Use Categories**	**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**
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
5E	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
Information Item	Forest Land converted to other Land-Use Categories	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
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
5	**Total Land-Use Categories**	**Gg N2O**	**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**
5C2	Land converted to Grassland	Gg N2O	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
5E	Settlements	Gg N2O	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 N2O	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 N2O	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	**Total 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**
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
5E	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
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
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
5	**Total 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**
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
5E	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
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
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

24.4 Appendix 4: Removals and Emissions by post-1990 afforestation and deforestation in the UK

- The following notes apply to all Tables

  Low, Mid, High refer to Emissions Scenarios;

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

  Mid means policy based or business as usual forestry proportion of UK planting of that occurred in 2004 distributed across England, Scotland, Wales and N. Ireland

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

  These data include, biomass, litter, soils and products.

  Products are small in the time period covered

  Units are Gg CO_2 per year

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

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

A (Mid) UK	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	28.4	0.0	135.7	12.4	1.3	17.5	195.2
1991	176.5	0.0	128.0	11.7	1.2	33.9	351.4
1992	208.2	0.0	121.7	11.2	1.1	49.4	391.6
1993	125.4	0.0	108.3	9.9	1.0	64.0	308.6
1994	-44.4	0.0	111.2	10.2	1.0	77.7	155.8
1995	-277.8	0.0	102.9	9.4	1.0	90.7	-73.8
1996	-522.5	0.0	119.4	10.9	1.1	102.9	-288.2
1997	-784.1	0.0	124.8	11.4	1.2	114.4	-532.3
1998	-1013.8	0.0	124.8	11.4	1.2	125.3	-751.0
1999	-1227.2	0.0	177.6	16.3	1.7	135.6	-896.1
2000	-1421.8	0.0	224.1	20.5	2.1	145.3	-1029.8
2001	-1586.3	0.0	269.1	24.7	2.5	154.4	-1135.6
2002	-1751.5	0.0	230.6	21.1	2.1	163.1	-1334.6
2003	-1953.7	0.0	222.8	20.4	2.1	171.3	-1537.1
2004	-2148.3	0.0	213.7	19.6	2.0	179.0	-1734.0
2005	-2332.2	0.0	212.0	19.4	2.0	186.3	-1912.6
2006	*-2501.3*	*0.0*	*191.2*	*17.5*	*1.8*	*193.2*	*-2097.6*
2007	*-2650.0*	*0.0*	*179.5*	*16.4*	*1.7*	*199.8*	*-2252.6*
2008	*-2793.0*	*0.0*	*170.8*	*15.7*	*1.6*	*206.0*	*-2398.9*
2009	*-2929.3*	*0.0*	*164.9*	*15.1*	*1.5*	*211.8*	*-2535.8*
2010	*-3107.4*	*0.0*	*172.8*	*15.8*	*1.6*	*217.4*	*-2699.7*
2011	*-3280.1*	*0.0*	*168.6*	*15.4*	*1.6*	*222.6*	*-2871.9*
2012	*-3449.3*	*0.0*	*162.7*	*14.9*	*1.5*	*227.6*	*-3042.5*
2013	*-3579.1*	*-21.4*	*150.6*	*13.8*	*1.4*	*232.3*	*-3181.0*
2014	*-3739.9*	*-6.5*	*153.2*	*14.0*	*1.4*	*236.8*	*-3334.4*
2015	*-3575.7*	*-209.5*	*153.1*	*14.0*	*1.4*	*241.1*	*-3166.0*
2016	*-3823.2*	*-94.3*	*145.9*	*13.4*	*1.4*	*245.1*	*-3417.5*
2017	*-4073.5*	*-24.9*	*137.4*	*12.6*	*1.3*	*248.9*	*-3673.3*
2018	*-4297.8*	*-0.6*	*135.0*	*12.4*	*1.3*	*252.5*	*-3896.6*
2019	*-4573.1*	*39.6*	*134.9*	*12.4*	*1.3*	*256.0*	*-4168.6*
2020	*-4284.4*	*-255.3*	*130.6*	*12.0*	*1.2*	*259.3*	*-3881.4*

B (Low) UK	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-2332.2**	**0.0**	**212.0**	**19.4**	**2.0**	**186.3**	**-1912.6**
2006	*-2467.6*	*0.0*	*188.6*	*17.3*	*1.8*	*193.2*	*-2066.8*
2007	*-2496.8*	*0.0*	*171.6*	*15.7*	*1.6*	*199.8*	*-2108.2*
2008	*-2609.4*	*0.0*	*154.8*	*14.2*	*1.4*	*206.0*	*-2232.9*
2009	*-2810.7*	*0.0*	*140.1*	*12.8*	*1.3*	*211.8*	*-2444.6*
2010	*-3144.8*	*0.0*	*138.2*	*12.7*	*1.3*	*217.4*	*-2775.3*
2011	*-3537.7*	*0.0*	*124.0*	*11.4*	*1.2*	*222.6*	*-3178.5*
2012	*-3953.2*	*0.0*	*108.2*	*9.9*	*1.0*	*227.6*	*-3606.5*
2013	*-4328.3*	*-21.4*	*85.9*	*7.9*	*0.8*	*232.3*	*-4001.3*
2014	*-4721.3*	*-6.5*	*78.4*	*7.2*	*0.7*	*236.8*	*-4398.1*
2015	*-4774.1*	*-209.5*	*68.9*	*6.3*	*0.6*	*241.1*	*-4457.2*
2016	*-5225.1*	*-94.3*	*55.0*	*5.0*	*0.5*	*245.1*	*-4919.5*
2017	*-5668.4*	*-24.9*	*39.2*	*3.6*	*0.4*	*248.9*	*-5376.3*
2018	*-6078.3*	*-0.6*	*36.9*	*3.4*	*0.3*	*252.5*	*-5785.1*
2019	*-6534.8*	*39.6*	*32.6*	*3.0*	*0.3*	*256.0*	*-6242.9*
2020	*-6425.4*	*-255.3*	*27.1*	*2.5*	*0.3*	*259.3*	*-6136.4*

C (High) UK	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-2332.2**	**0.0**	**212.0**	**19.4**	**2.0**	**186.3**	**-1912.6**
2006	*-2521.7*	*0.0*	*193.8*	*17.8*	*1.8*	*193.2*	*-2115.1*
2007	*-2742.3*	*0.0*	*187.4*	*17.2*	*1.7*	*199.8*	*-2336.2*
2008	*-2903.6*	*0.0*	*186.8*	*17.1*	*1.7*	*206.0*	*-2492.0*
2009	*-3000.7*	*0.0*	*189.8*	*17.4*	*1.8*	*211.8*	*-2579.9*
2010	*-3084.8*	*0.0*	*207.5*	*19.0*	*1.9*	*217.4*	*-2639.0*
2011	*-3124.9*	*0.0*	*213.1*	*19.5*	*2.0*	*222.6*	*-2667.6*
2012	*-3145.5*	*0.0*	*217.2*	*19.9*	*2.0*	*227.6*	*-2678.7*
2013	*-3127.5*	*-21.4*	*215.2*	*19.7*	*2.0*	*232.3*	*-2658.2*
2014	*-3148.2*	*-6.5*	*228.0*	*20.9*	*2.1*	*236.8*	*-2660.4*
2015	*-2853.1*	*-209.5*	*238.1*	*21.8*	*2.2*	*241.1*	*-2349.9*
2016	*-2978.0*	*-94.3*	*241.2*	*22.1*	*2.2*	*245.1*	*-2467.4*
2017	*-3111.9*	*-24.9*	*243.0*	*22.3*	*2.3*	*248.9*	*-2595.4*
2018	*-3224.3*	*-0.6*	*250.9*	*23.0*	*2.3*	*252.5*	*-2695.5*
2019	*-3390.4*	*39.6*	*261.2*	*23.9*	*2.4*	*256.0*	*-2846.9*
2020	*-2993.6*	*-255.3*	*267.3*	*24.5*	*2.5*	*259.3*	*-2440.1*

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

A (Mid) England	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	-3.3	0.0	97.4	8.9	0.9	12.5	116.5
1991	2.9	0.0	92.0	8.4	0.9	24.4	128.5
1992	-2.4	0.0	87.4	8.0	0.8	35.5	129.3
1993	-28.6	0.0	77.8	7.1	0.7	46.0	103.0
1994	-69.2	0.0	79.9	7.3	0.7	55.8	74.6
1995	-123.7	0.0	73.9	6.8	0.7	65.1	22.9
1996	-194.6	0.0	85.7	7.9	0.8	73.9	-26.3
1997	-271.1	0.0	89.6	8.2	0.8	82.2	-90.3
1998	-344.2	0.0	89.7	8.2	0.8	90.0	-155.5
1999	-410.8	0.0	127.6	11.7	1.2	97.4	-173.0
2000	-465.3	0.0	160.9	14.7	1.5	104.3	-183.8
2001	-512.7	0.0	193.2	17.7	1.8	110.9	-189.1
2002	-560.3	0.0	165.6	15.2	1.5	117.1	-260.9
2003	-612.4	0.0	160.0	14.7	1.5	123.0	-313.2
2004	-664.2	0.0	153.5	14.1	1.4	128.6	-366.7
2005	-721.5	0.0	152.2	14.0	1.4	133.8	-420.1
2006	*-772.9*	*0.0*	*137.3*	*12.6*	*1.3*	*138.8*	*-483.0*
2007	*-821.9*	*0.0*	*128.9*	*11.8*	*1.2*	*143.5*	*-536.5*
2008	*-869.4*	*0.0*	*122.7*	*11.2*	*1.1*	*147.9*	*-586.4*
2009	*-917.0*	*0.0*	*118.5*	*10.9*	*1.1*	*152.1*	*-634.5*
2010	*-969.2*	*0.0*	*124.1*	*11.4*	*1.2*	*156.1*	*-676.4*
2011	*-1023.3*	*0.0*	*121.1*	*11.1*	*1.1*	*159.9*	*-730.1*
2012	*-1078.7*	*0.0*	*116.9*	*10.7*	*1.1*	*163.5*	*-786.6*
2013	*-1136.7*	*0.0*	*108.1*	*9.9*	*1.0*	*166.9*	*-850.8*
2014	*-1189.3*	*0.0*	*110.0*	*10.1*	*1.0*	*170.1*	*-898.1*
2015	*-1229.9*	*-13.8*	*110.0*	*10.1*	*1.0*	*173.1*	*-935.7*
2016	*-1300.0*	*-7.6*	*104.8*	*9.6*	*1.0*	*176.0*	*-1008.7*
2017	*-1372.5*	*-1.2*	*98.7*	*9.0*	*0.9*	*178.8*	*-1085.1*
2018	*-1436.2*	*-3.2*	*97.0*	*8.9*	*0.9*	*181.4*	*-1148.1*
2019	*-1520.7*	*2.7*	*96.9*	*8.9*	*0.9*	*183.8*	*-1230.3*
2020	*-1539.4*	*-28.6*	*93.8*	*8.6*	*0.9*	*186.2*	*-1250.0*

B (Low) England	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
2005	**-721.5**	**0.0**	**152.2**	**14.0**	**1.4**	**133.8**	**-420.1**
2006	*-775.2*	*0.0*	*135.4*	*12.4*	*1.3*	*138.8*	*-487.4*
2007	*-806.2*	*0.0*	*123.2*	*11.3*	*1.1*	*143.5*	*-527.1*
2008	*-867.2*	*0.0*	*111.2*	*10.2*	*1.0*	*147.9*	*-596.8*
2009	*-963.6*	*0.0*	*100.6*	*9.2*	*0.9*	*152.1*	*-700.7*
2010	*-1098.8*	*0.0*	*99.3*	*9.1*	*0.9*	*156.1*	*-833.4*
2011	*-1259.7*	*0.0*	*89.1*	*8.2*	*0.8*	*159.9*	*-1001.7*
2012	*-1430.4*	*0.0*	*77.7*	*7.1*	*0.7*	*163.5*	*-1181.4*
2013	*-1601.2*	*0.0*	*61.7*	*5.7*	*0.6*	*166.9*	*-1366.4*
2014	*-1759.5*	*0.0*	*56.3*	*5.2*	*0.5*	*170.1*	*-1527.5*
2015	*-1898.1*	*-13.8*	*49.5*	*4.5*	*0.5*	*173.1*	*-1670.5*
2016	*-2059.4*	*-7.6*	*39.5*	*3.6*	*0.4*	*176.0*	*-1839.9*
2017	*-2217.5*	*-1.2*	*28.2*	*2.6*	*0.3*	*178.8*	*-2007.7*
2018	*-2362.8*	*-3.2*	*26.5*	*2.4*	*0.2*	*181.4*	*-2152.3*
2019	*-2526.3*	*2.7*	*23.4*	*2.1*	*0.2*	*183.8*	*-2316.7*
2020	*-2622.3*	*-28.6*	*19.4*	*1.8*	*0.2*	*186.2*	*-2414.6*

C (High) England	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-721.5**	**0.0**	**152.2**	**14.0**	**1.4**	**133.8**	**-420.1**
2006	*-771.5*	*0.0*	*139.2*	*12.8*	*1.3*	*138.8*	*-479.5*
2007	*-831.4*	*0.0*	*134.6*	*12.3*	*1.3*	*143.5*	*-539.7*
2008	*-870.7*	*0.0*	*134.1*	*12.3*	*1.2*	*147.9*	*-575.1*
2009	*-889.0*	*0.0*	*136.3*	*12.5*	*1.3*	*152.1*	*-586.7*
2010	*-891.0*	*0.0*	*149.0*	*13.7*	*1.4*	*156.1*	*-570.9*
2011	*-880.7*	*0.0*	*153.0*	*14.0*	*1.4*	*159.9*	*-552.4*
2012	*-866.7*	*0.0*	*156.0*	*14.3*	*1.5*	*163.5*	*-531.4*
2013	*-856.6*	*0.0*	*154.5*	*14.2*	*1.4*	*166.9*	*-519.6*
2014	*-845.4*	*0.0*	*163.7*	*15.0*	*1.5*	*170.1*	*-495.1*
2015	*-827.0*	*-13.8*	*171.0*	*15.7*	*1.6*	*173.1*	*-465.6*
2016	*-842.2*	*-7.6*	*173.2*	*15.9*	*1.6*	*176.0*	*-475.5*
2017	*-863.1*	*-1.2*	*174.5*	*16.0*	*1.6*	*178.8*	*-492.2*
2018	*-877.5*	*-3.2*	*180.2*	*16.5*	*1.7*	*181.4*	*-497.7*
2019	*-914.5*	*2.7*	*187.6*	*17.2*	*1.7*	*183.8*	*-524.2*
2020	*-886.6*	*-28.6*	*192.0*	*17.6*	*1.8*	*186.2*	*-489.1*

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

A (Mid) Scotland	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	30.8	0.0	30.5	2.8	0.3	3.9	68.3
1991	159.1	0.0	28.8	2.6	0.3	7.6	198.4
1992	196.9	0.0	27.4	2.5	0.3	11.1	238.2
1993	152.4	0.0	24.4	2.2	0.2	14.4	193.6
1994	38.3	0.0	25.0	2.3	0.2	17.5	83.3
1995	-120.4	0.0	23.2	2.1	0.2	20.4	-74.5
1996	-268.5	0.0	26.9	2.5	0.2	23.2	-215.8
1997	-429.9	0.0	28.1	2.6	0.3	25.7	-373.2
1998	-563.4	0.0	28.1	2.6	0.3	28.2	-504.3
1999	-690.4	0.0	40.0	3.7	0.4	30.5	-615.9
2000	-814.8	0.0	50.4	4.6	0.5	32.7	-726.6
2001	-919.5	0.0	60.5	5.5	0.6	34.7	-818.1
2002	-1022.7	0.0	51.9	4.8	0.5	36.7	-928.9
2003	-1158.1	0.0	50.1	4.6	0.5	38.5	-1064.4
2004	-1286.4	0.0	48.1	4.4	0.4	40.3	-1193.1
2005	-1399.3	0.0	47.7	4.4	0.4	41.9	-1304.9
2006	*-1503.8*	*0.0*	*43.0*	*3.9*	*0.4*	*43.5*	*-1412.9*
2007	*-1591.6*	*0.0*	*40.4*	*3.7*	*0.4*	*45.0*	*-1502.2*
2008	*-1671.0*	*0.0*	*38.4*	*3.5*	*0.4*	*46.3*	*-1582.3*
2009	*-1745.3*	*0.0*	*37.1*	*3.4*	*0.3*	*47.7*	*-1656.7*
2010	*-1857.1*	*0.0*	*38.9*	*3.6*	*0.4*	*48.9*	*-1765.3*
2011	*-1960.7*	*0.0*	*37.9*	*3.5*	*0.4*	*50.1*	*-1868.8*
2012	*-2060.3*	*0.0*	*36.6*	*3.4*	*0.3*	*51.2*	*-1968.8*
2013	*-2155.8*	*0.0*	*33.9*	*3.1*	*0.3*	*52.3*	*-2066.2*
2014	*-2240.0*	*0.0*	*34.5*	*3.2*	*0.3*	*53.3*	*-2148.8*
2015	*-2021.1*	*-190.6*	*34.5*	*3.2*	*0.3*	*54.2*	*-1928.9*
2016	*-2190.2*	*-79.2*	*32.8*	*3.0*	*0.3*	*55.1*	*-2098.9*
2017	*-2344.8*	*-23.8*	*30.9*	*2.8*	*0.3*	*56.0*	*-2254.7*
2018	*-2514.1*	*16.1*	*30.4*	*2.8*	*0.3*	*56.8*	*-2423.8*
2019	*-2684.3*	*42.3*	*30.3*	*2.8*	*0.3*	*57.6*	*-2593.3*
2020	*-2363.1*	*-222.1*	*29.4*	*2.7*	*0.3*	*58.3*	*-2272.4*

B (Low) Scotland	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
2005	**-1399.3**	**0.0**	**47.7**	**4.4**	**0.4**	**41.9**	**-1304.9**
2006	*-1470.0*	*0.0*	*42.4*	*3.9*	*0.4*	*43.5*	*-1379.8*
2007	*-1464.6*	*0.0*	*38.6*	*3.5*	*0.4*	*45.0*	*-1377.2*
2008	*-1501.6*	*0.0*	*34.8*	*3.2*	*0.3*	*46.3*	*-1416.9*
2009	*-1586.2*	*0.0*	*31.5*	*2.9*	*0.3*	*47.7*	*-1503.8*
2010	*-1758.0*	*0.0*	*31.1*	*2.8*	*0.3*	*48.9*	*-1674.9*
2011	*-1957.0*	*0.0*	*27.9*	*2.6*	*0.3*	*50.1*	*-1876.2*
2012	*-2167.9*	*0.0*	*24.3*	*2.2*	*0.2*	*51.2*	*-2089.9*
2013	*-2376.1*	*0.0*	*19.3*	*1.8*	*0.2*	*52.3*	*-2302.5*
2014	*-2568.2*	*0.0*	*17.6*	*1.6*	*0.2*	*53.3*	*-2495.5*
2015	*-2451.0*	*-190.6*	*15.5*	*1.4*	*0.1*	*54.2*	*-2379.7*
2016	*-2716.3*	*-79.2*	*12.4*	*1.1*	*0.1*	*55.1*	*-2647.5*
2017	*-2962.8*	*-23.8*	*8.8*	*0.8*	*0.1*	*56.0*	*-2897.1*
2018	*-3221.3*	*16.1*	*8.3*	*0.8*	*0.1*	*56.8*	*-3155.4*
2019	*-3479.6*	*42.3*	*7.3*	*0.7*	*0.1*	*57.6*	*-3413.9*
2020	*-3246.3*	*-222.1*	*6.1*	*0.6*	*0.1*	*58.3*	*-3181.2*

C (High) Scotland	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-1399.3**	**0.0**	**47.7**	**4.4**	**0.4**	**41.9**	**-1304.9**
2006	*-1524.1*	*0.0*	*43.6*	*4.0*	*0.4*	*43.5*	*-1432.7*
2007	*-1668.2*	*0.0*	*42.2*	*3.9*	*0.4*	*45.0*	*-1576.8*
2008	*-1773.1*	*0.0*	*42.0*	*3.9*	*0.4*	*46.3*	*-1680.5*
2009	*-1841.2*	*0.0*	*42.7*	*3.9*	*0.4*	*47.7*	*-1746.5*
2010	*-1916.8*	*0.0*	*46.7*	*4.3*	*0.4*	*48.9*	*-1816.5*
2011	*-1962.9*	*0.0*	*47.9*	*4.4*	*0.4*	*50.1*	*-1860.0*
2012	*-1995.5*	*0.0*	*48.9*	*4.5*	*0.5*	*51.2*	*-1890.4*
2013	*-2023.0*	*0.0*	*48.4*	*4.4*	*0.5*	*52.3*	*-1917.4*
2014	*-2042.2*	*0.0*	*51.3*	*4.7*	*0.5*	*53.3*	*-1932.4*
2015	*-1761.9*	*-190.6*	*53.6*	*4.9*	*0.5*	*54.2*	*-1648.7*
2016	*-1873.0*	*-79.2*	*54.3*	*5.0*	*0.5*	*55.1*	*-1758.1*
2017	*-1972.2*	*-23.8*	*54.7*	*5.0*	*0.5*	*56.0*	*-1856.0*
2018	*-2087.6*	*16.1*	*56.5*	*5.2*	*0.5*	*56.8*	*-1968.6*
2019	*-2204.9*	*42.3*	*58.8*	*5.4*	*0.5*	*57.6*	*-2082.6*
2020	*-1830.6*	*-222.1*	*60.1*	*5.5*	*0.6*	*58.3*	*-1706.1*

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

A (Mid) Wales	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	-1.3	0.0	7.7	0.7	0.1	1.0	8.2
1991	-0.3	0.0	7.3	0.7	0.1	1.9	9.6
1992	-2.0	0.0	6.9	0.6	0.1	2.8	8.4
1993	-6.0	0.0	6.2	0.6	0.1	3.6	4.4
1994	-12.0	0.0	6.3	0.6	0.1	4.4	-0.6
1995	-18.3	0.0	5.8	0.5	0.1	5.2	-6.7
1996	-25.4	0.0	6.8	0.6	0.1	5.8	-12.1
1997	-32.9	0.0	7.1	0.6	0.1	6.5	-18.6
1998	-40.2	0.0	7.1	0.6	0.1	7.1	-25.2
1999	-46.5	0.0	10.1	0.9	0.1	7.7	-27.7
2000	-52.0	0.0	12.7	1.2	0.1	8.3	-29.8
2001	-57.0	0.0	15.3	1.4	0.1	8.8	-31.4
2002	-63.5	0.0	13.1	1.2	0.1	9.3	-39.8
2003	-70.5	0.0	12.7	1.2	0.1	9.7	-46.8
2004	-76.3	0.0	12.1	1.1	0.1	10.2	-52.7
2005	-80.4	0.0	12.0	1.1	0.1	10.6	-56.5
2006	*-83.7*	*0.0*	*10.9*	*1.0*	*0.1*	*11.0*	*-60.7*
2007	*-87.2*	*0.0*	*10.2*	*0.9*	*0.1*	*11.3*	*-64.7*
2008	*-91.7*	*0.0*	*9.7*	*0.9*	*0.1*	*11.7*	*-69.3*
2009	*-97.2*	*0.0*	*9.4*	*0.9*	*0.1*	*12.0*	*-74.8*
2010	*-104.5*	*0.0*	*9.8*	*0.9*	*0.1*	*12.3*	*-81.3*
2011	*-111.6*	*0.0*	*9.6*	*0.9*	*0.1*	*12.6*	*-88.4*
2012	*-118.5*	*0.0*	*9.2*	*0.8*	*0.1*	*12.9*	*-95.4*
2013	*-125.2*	*0.0*	*8.6*	*0.8*	*0.1*	*13.2*	*-102.6*
2014	*-131.5*	*0.0*	*8.7*	*0.8*	*0.1*	*13.5*	*-108.4*
2015	*-128.6*	*-6.0*	*8.7*	*0.8*	*0.1*	*13.7*	*-105.3*
2016	*-139.6*	*-1.6*	*8.3*	*0.8*	*0.1*	*13.9*	*-116.6*
2017	*-150.0*	*0.7*	*7.8*	*0.7*	*0.1*	*14.1*	*-127.3*
2018	*-160.3*	*1.9*	*7.7*	*0.7*	*0.1*	*14.3*	*-137.5*
2019	*-168.1*	*0.8*	*7.7*	*0.7*	*0.1*	*14.5*	*-145.1*
2020	*-164.1*	*-6.6*	*7.4*	*0.7*	*0.1*	*14.7*	*-141.2*

B (Low) Wales	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-80.4**	**0.0**	**12.0**	**1.1**	**0.1**	**10.6**	**-56.5**
2006	*-83.9*	*0.0*	*10.7*	*1.0*	*0.1*	*11.0*	*-61.1*
2007	*-85.4*	*0.0*	*9.7*	*0.9*	*0.1*	*11.3*	*-63.3*
2008	*-91.4*	*0.0*	*8.8*	*0.8*	*0.1*	*11.7*	*-70.0*
2009	*-102.3*	*0.0*	*8.0*	*0.7*	*0.1*	*12.0*	*-81.5*
2010	*-119.0*	*0.0*	*7.9*	*0.7*	*0.1*	*12.3*	*-98.0*
2011	*-138.2*	*0.0*	*7.0*	*0.6*	*0.1*	*12.6*	*-117.8*
2012	*-158.2*	*0.0*	*6.1*	*0.6*	*0.1*	*12.9*	*-138.5*
2013	*-177.6*	*0.0*	*4.9*	*0.4*	*0.0*	*13.2*	*-159.1*
2014	*-195.9*	*0.0*	*4.5*	*0.4*	*0.0*	*13.5*	*-177.5*
2015	*-204.0*	*-6.0*	*3.9*	*0.4*	*0.0*	*13.7*	*-186.0*
2016	*-225.4*	*-1.6*	*3.1*	*0.3*	*0.0*	*13.9*	*-208.1*
2017	*-245.5*	*0.7*	*2.2*	*0.2*	*0.0*	*14.1*	*-228.9*
2018	*-265.0*	*1.9*	*2.1*	*0.2*	*0.0*	*14.3*	*-248.3*
2019	*-281.7*	*0.8*	*1.9*	*0.2*	*0.0*	*14.5*	*-265.1*
2020	*-286.5*	*-6.6*	*1.5*	*0.1*	*0.0*	*14.7*	*-270.1*

C (High) Wales	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-80.4**	**0.0**	**12.0**	**1.1**	**0.1**	**10.6**	**-56.5**
2006	*-83.5*	*0.0*	*11.0*	*1.0*	*0.1*	*11.0*	*-60.4*
2007	*-88.3*	*0.0*	*10.6*	*1.0*	*0.1*	*11.3*	*-65.3*
2008	*-91.9*	*0.0*	*10.6*	*1.0*	*0.1*	*11.7*	*-68.6*
2009	*-94.1*	*0.0*	*10.8*	*1.0*	*0.1*	*12.0*	*-70.2*
2010	*-95.7*	*0.0*	*11.8*	*1.1*	*0.1*	*12.3*	*-70.4*
2011	*-95.6*	*0.0*	*12.1*	*1.1*	*0.1*	*12.6*	*-69.6*
2012	*-94.6*	*0.0*	*12.3*	*1.1*	*0.1*	*12.9*	*-68.1*
2013	*-93.6*	*0.0*	*12.2*	*1.1*	*0.1*	*13.2*	*-67.0*
2014	*-92.7*	*0.0*	*13.0*	*1.2*	*0.1*	*13.5*	*-64.9*
2015	*-83.1*	*-6.0*	*13.5*	*1.2*	*0.1*	*13.7*	*-54.5*
2016	*-87.9*	*-1.6*	*13.7*	*1.3*	*0.1*	*13.9*	*-58.9*
2017	*-92.4*	*0.7*	*13.8*	*1.3*	*0.1*	*14.1*	*-63.1*
2018	*-97.1*	*1.9*	*14.3*	*1.3*	*0.1*	*14.3*	*-67.1*
2019	*-99.6*	*0.8*	*14.8*	*1.4*	*0.1*	*14.5*	*-68.7*
2020	*-90.4*	*-6.6*	*15.2*	*1.4*	*0.1*	*14.7*	*-58.9*

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

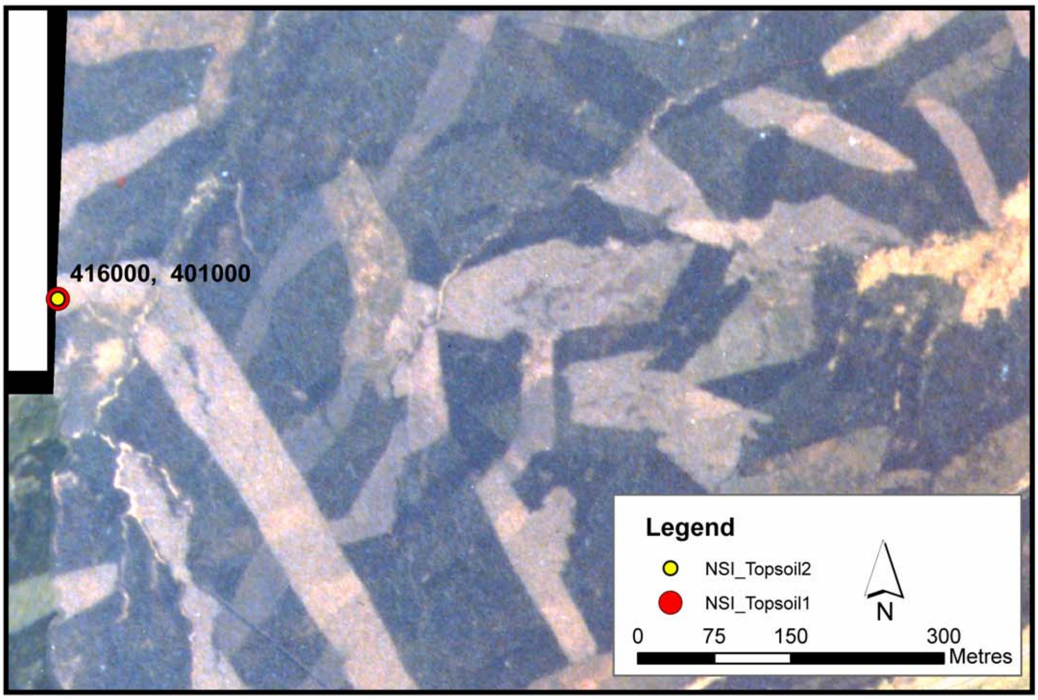
A (Mid) N. Ireland	**Afforestation**		**Deforestation**				**Art 3.3 (excludes HWP)**
Gg CO_2 /year or GWP equiv Gg CO_2/year	**Biomass stocks**	**Harvested Wood Products**	**Immediate loss (Biomass) CO_2**	**Immediate loss (Biomass) CH_4**	**Immediate loss (Biomass) N_2O**	**Delayed loss (Soil) CO_2**	**Afforestation + Deforestation**
1990	2.2	0.0	**0.0**	**0.0**	**0.0**	**0.0**	2.2
1991	14.9	0.0	0.0	0.0	0.0	0.0	14.9
1992	15.7	0.0	0.0	0.0	0.0	0.0	15.7
1993	7.6	0.0	0.0	0.0	0.0	0.0	7.6
1994	-1.5	0.0	0.0	0.0	0.0	0.0	-1.5
1995	-15.5	0.0	**0.0**	**0.0**	**0.0**	**0.0**	-15.5
1996	-34.0	0.0	0.0	0.0	0.0	0.0	-34.0
1997	-50.2	0.0	0.0	0.0	0.0	0.0	-50.2
1998	-66.0	0.0	0.0	0.0	0.0	0.0	-66.0
1999	-79.6	0.0	0.0	0.0	0.0	0.0	-79.6
2000	-89.6	0.0	**0.0**	**0.0**	**0.0**	**0.0**	-89.6
2001	-97.1	0.0	0.0	0.0	0.0	0.0	-97.1
2002	-105.0	0.0	0.0	0.0	0.0	0.0	-105.0
2003	-112.7	0.0	0.0	0.0	0.0	0.0	-112.7
2004	-121.5	0.0	0.0	0.0	0.0	0.0	-121.5
2005	-131.0	0.0	***0.0***	***0.0***	***0.0***	***0.0***	-131.0
2006	*-141.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-141.0*
2007	*-149.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-149.3*
2008	*-160.8*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-160.8*
2009	*-169.8*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-169.8*
2010	*-176.7*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-176.7*
2011	*-184.6*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-184.6*
2012	*-191.7*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-191.7*
2013	*-161.4*	*-21.4*	*0.0*	*0.0*	*0.0*	*0.0*	*-161.4*
2014	*-179.1*	*-6.5*	*0.0*	*0.0*	*0.0*	*0.0*	*-179.1*
2015	*-196.1*	*0.9*	***0.0***	***0.0***	***0.0***	***0.0***	*-196.1*
2016	*-193.3*	*-5.9*	*0.0*	*0.0*	*0.0*	*0.0*	*-193.3*
2017	*-206.1*	*-0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*-206.1*
2018	*-187.3*	*-15.3*	*0.0*	*0.0*	*0.0*	*0.0*	*-187.3*
2019	*-199.9*	*-6.2*	*0.0*	*0.0*	*0.0*	*0.0*	*-199.9*
2020	*-217.7*	*1.9*	***0.0***	***0.0***	***0.0***	***0.0***	*-217.7*

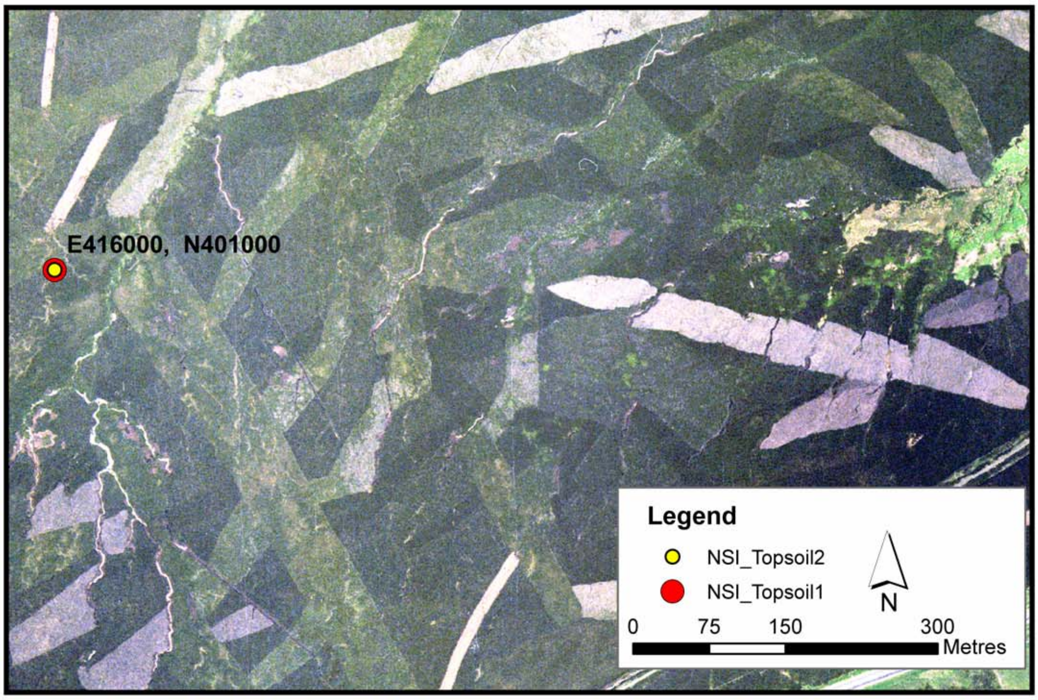
B (Low) N. Ireland	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-131.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-131.0**
2006	*-138.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-138.5*
2007	*-140.6*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-140.6*
2008	*-149.3*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-149.3*
2009	*-158.6*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-158.6*
2010	*-169.0*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-169.0*
2011	*-182.7*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-182.7*
2012	*-196.7*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-196.7*
2013	*-173.3*	*-21.4*	*0.0*	*0.0*	*0.0*	*0.0*	*-173.3*
2014	*-197.6*	*-6.5*	*0.0*	*0.0*	*0.0*	*0.0*	*-197.6*
2015	*-220.9*	*0.9*	***0.0***	***0.0***	***0.0***	***0.0***	*-220.9*
2016	*-224.1*	*-5.9*	*0.0*	*0.0*	*0.0*	*0.0*	*-224.1*
2017	*-242.6*	*-0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*-242.6*
2018	*-229.2*	*-15.3*	*0.0*	*0.0*	*0.0*	*0.0*	*-229.2*
2019	*-247.2*	*-6.2*	*0.0*	*0.0*	*0.0*	*0.0*	*-247.2*
2020	*-270.4*	*1.9*	***0.0***	***0.0***	***0.0***	***0.0***	*-270.4*

C (High) N. Ireland	Afforestation		Deforestation				Art 3.3 (excludes HWP)
Gg CO_2 /year or GWP equiv Gg CO_2/year	Biomass stocks	Harvested Wood Products	Immediate loss (Biomass) CO_2	Immediate loss (Biomass) CH_4	Immediate loss (Biomass) N_2O	Delayed loss (Soil) CO_2	Afforestation + Deforestation
2005	**-131.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-131.0**
2006	*-142.4*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-142.4*
2007	*-154.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-154.5*
2008	*-167.8*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-167.8*
2009	*-176.5*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-176.5*
2010	*-181.3*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-181.3*
2011	*-185.7*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-185.7*
2012	*-188.7*	*0.0*	***0.0***	***0.0***	***0.0***	***0.0***	*-188.7*
2013	*-154.2*	*-21.4*	*0.0*	*0.0*	*0.0*	*0.0*	*-154.2*
2014	*-167.9*	*-6.5*	*0.0*	*0.0*	*0.0*	*0.0*	*-167.9*
2015	*-181.2*	*0.9*	***0.0***	***0.0***	***0.0***	***0.0***	*-181.2*
2016	*-174.8*	*-5.9*	*0.0*	*0.0*	*0.0*	*0.0*	*-174.8*
2017	*-184.2*	*-0.6*	*0.0*	*0.0*	*0.0*	*0.0*	*-184.2*
2018	*-162.0*	*-15.3*	*0.0*	*0.0*	*0.0*	*0.0*	*-162.0*
2019	*-171.4*	*-6.2*	*0.0*	*0.0*	*0.0*	*0.0*	*-171.4*
2020	*-186.0*	*1.9*	***0.0***	***0.0***	***0.0***	***0.0***	*-186.0*

Appendix 1 to NSRI's annual report for Work package 2.8

Aerial photography taken in 1989 (top) and 1995 (bottom) at three NSI sites



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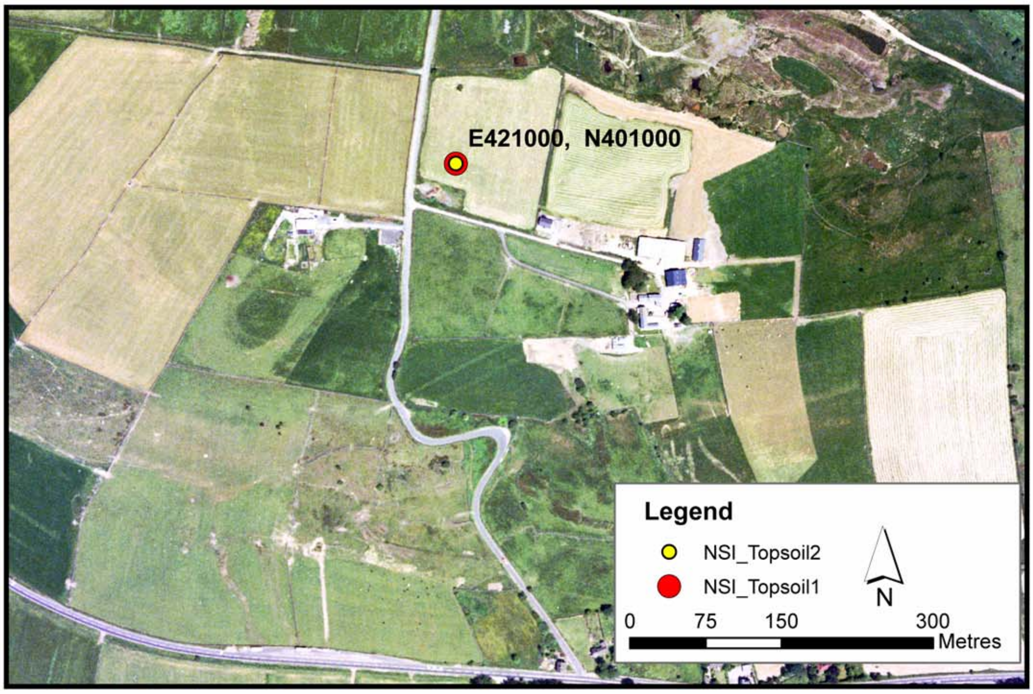
Metres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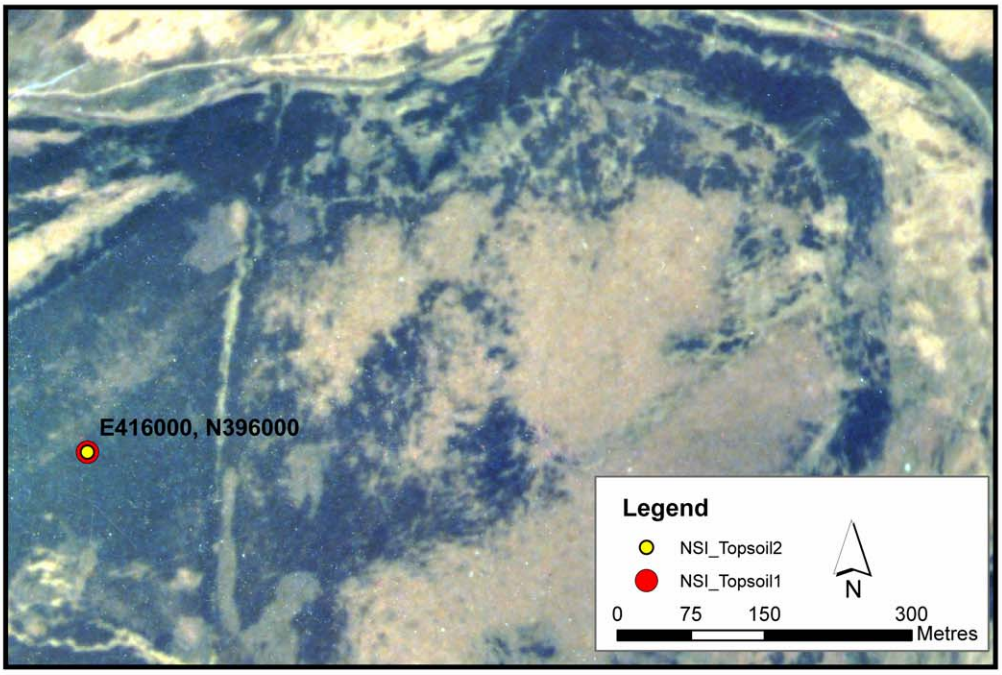
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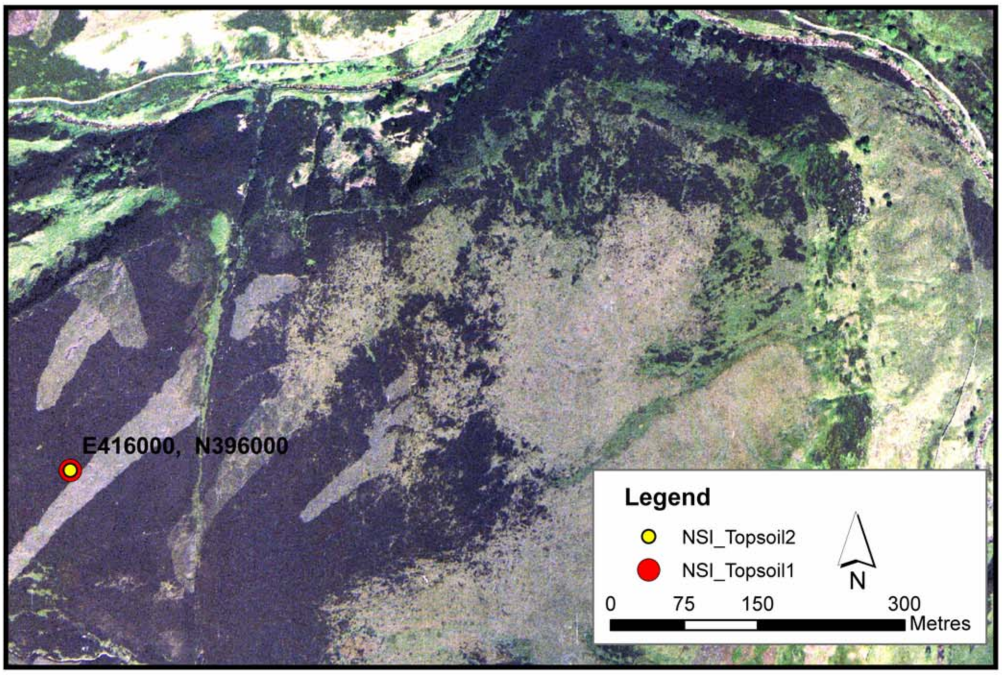
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