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.