Report

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PILOT PROJECT TO DETERMINE THE SUITABILITY OF INTEGRATED ADMINISTRATION AND CONTROL SYSTEM (IACS) DATA TO PROVIDE LAND USE CHANGE DATA FOR ANNUAL GREENHOUSE GAS EMISSION ESTIMATES

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1. Executive Summary

Objectives

The objectives of this study were:

- To produce a land use change inventory for Scotland using annual IACS data held by the Scottish Government suitable for use with the Estimating Carbon in Organic Soils - Sequestration and Emissions (ECOSSE) model to simulate changes in soil carbon stocks resulting from these observed land use changes.

- To compare and contrast the results with the current greenhouse gas (GHG) emissions inventory for the land use and land use change sectors, highlighting the strengths and weaknesses of both approaches, and provide a commentary on those results

- To determine how underlying soils data for land use categories important for Scotland such as semi-natural and forestry could be better represented.

- To provide clear analysis and guidance on the implications of different methods and approaches in producing an assessment of land use change and a GHG emissions inventory for Scotland on an annual basis.

Overall conclusions

The main conclusions from this study are as follows:

1. It is feasible to use IACS land use change data along with the ECOSSE model to simulate changes in soil C stock for Scotland, and to compare these with estimates using the current method which uses Countryside Survey (CS) land use change data and the carbon flow (CFlow) model to simulate net emissions

2. Spatial and temporal resolution of IACS land use data is far superior to data obtained from the Countryside Survey (CS), improving spatial resolution by a factor of 40,000 and temporal resolution by a factor of 10. CS data was never designed to provide annual land use change data on a sufficiently accurate spatial scale for GHG inventory purposes hence it is collected every 10 years on a large 10km grid

3. Limitations in the reliability of IACS data are associated with data holes (due to all land not being reported under IACS), and classification creep (due to changing payments causing systematic changes in the way the land use is classified).

4. Problems with classification creep will be reduced as classifications become more stable. By accounting for land use in successive years, the definition of more uncertain land use categories (such as grassland and semi-natural) can be resolved.

5. Future cross-checking IACS data against other available information on land use change will validate and improve confidence in IACS data whilst maintaining the higher resolution.

6. Mining of data from existing sources such as the Scottish Soils Knowledge & Information Base (SSKIB) and the Biosoils dataset has the potential to improve the estimated soil characteristics for semi-natural and forested soils, but is likely to require further targeted measurements to fill remaining gaps as there are not enough historical sample sites for these 2 land use categories but significantly they tend to be highly associated with organic soils

Land use change for Scotland using annual IACS data

The current GHG inventory for Scotland (and the rest of the UK) uses land use change data derived from the Countryside Survey (CS) and the Forestry Commission (termed Land Use & Land Use Change from Forestry LULUCF). CS data is used to drive a model called CFlow to simulate turnover of soil organic matter (SOM) and hence predict the emissions and sinks from this sector. In 2007 the Scottish and Welsh Assembly Governments funded the development of a model (ECOSSE) to simulate the response of organic (as well as organo-mineral soils) to land use and climate change, and is suited to Scottish and Welsh soils where a high proportion of them are classified as either peat or peaty. IACS data provides extensive, high resolution annual land use data for Scotland and since 2000 the coverage has greatly increased (currently 5.7 million ha) and it is also spatially explicit. The most significant limitation in IACS is forest cover which is under represented with less than 30% of Scotland's woodland recorded in the system. IACS is the only spatial land use dataset updated on an annual basis.

Protocols for access to IACS data for research use and for translation of the data into input files for ECOSSE and the current GHG inventory have been established using unique combinations of land use, land use change, soil, and climate. Soils and land use data are at a 100m grid resolution, compared to the land use data obtained from the Countryside Survey which is on a 20km grid and collated on a 10 year cycle. Therefore, the spatial and temporal resolution of simulations of GHG emissions from land use change using IACS data has resulted in an immediate improvement in the inventory.

Limitations of the IACS dataset include the problem of classification reliability and creep. From 2009 there is a commitment to the collection of the land use classes required by the June Agricultural Census and these are sufficiently specific to be used to drive models such as ECOSSE and CFlow to produce the inventory. There is, however, the need for care in interpreting annual change in land use, especially for land uses near the boundaries of classes, such as grassland and semi-natural, where past classification may have changed in response to other drivers such as Single Farm Payment cross compliance criteria. Therefore IACS data since 2000 will be more reliable and stable in terms of classification.

Comparison of results using IACS land use change data with CS land use change data using the CFlow model

The resolution of the simulations using IACS data is much finer than those from the Countryside Survey, and so allows more accurate determination of the interactions between soil type and land use change. In the work presented here, land use data to a resolution of a 100m grid were provided by the IACS data, whereas the land use change data provided in the CS are at a resolution of a 20km grid. However, as discussed above, there is some question over the stability of the land use classifications provided by farmers before 2009 because the definition given is influenced by the changing nature of payments farmers receive. This is especially true for the classification of grassland and semi-natural land use, resulting in an apparent large conversion of grassland to semi-natural being recorded by IACS 2000-2009. Future data should have improved stability of classification due to the collection of land use classes required by the June Agricultural Census.

If the semi-natural and grassland land use types are combined, the higher resolution of the data provided by IACS results in a 66% increase in the soil C losses simulated using the ECOSSE model in the first decade, but only a 2% increase in the current GHG inventory simulation using CFlow. This difference is due to the way that the two models deal with the dynamics of soil C turnover and will decline over time as the soil C loss simulated by ECOSSE declines as land recovers from cultivation and plant communities reach maturity. Differences in land use change recorded by the CS and IACS account for 80% of the difference observed in the soil C changes simulated.

IACS data are likely to be more representative of the farm industry and agricultural land use than the CS data and using it in combination with fine scale soil series data provides improved soil carbon density estimates. IACS data are available annually, which will improve the temporal as well as the spatial resolution of any GHG inventory estimates derived using this data.

Better representation of soils data for land use categories important for Scotland, including semi-natural and forestry

There are a range of options to identify and update the required input data for carbon modelling. These include augmenting a minimal dataset that is partially available and extracting all the relevant horizon sequence, depth and morphological data from approximately 1100 soil profiles (870 + 220) held in the Scottish Soils Database. It is unlikely that there are sufficient soil profiles to provide summary data for all soil series even excluding those unlikely to be afforested. Calculating horizon sequences, depths and summary data at the level of major soil subgroup may also not provide all the required data but the main soil subgroups are likely to be represented. There are a number of soil profiles for which analytical data is available in electronic format but where the vegetation type has not been transferred from profile cards to the database. Once the data mining of the Scottish Soil Database has been exhausted, additional data sources such as the Biosoils dataset and Forest Research soil profile data could be explored. Once these options have been exhausted, gaps in the data should be filled by targeted soil sampling to ensure adequate coverage of important land use categories for Scotland. The Scottish Government intends to support this activity through its underpinning capacity funding to its main research providers.

Analysis of different methods used to produce an assessment of land use change and a greenhouse gas emissions inventory for Scotland on an annual basis

IACS data has great potential to produce improved estimates of agricultural land use change and a GHG emissions inventory for Scotland on an annual basis. The improved resolution of the data is likely to increase estimates of losses in soil carbon by as much as 66% in the first decade following land use change. Problems with classification creep will be resolved as land use categories become more established. The integration of IACS with the National Forest Inventory should be a priority, as this could greatly improve the coverage of land use data. Greater specificity in land use and management options could be achieved by expanding the land use classes to correspond to the IACS classifications, rather than reducing the IACS classifications to match those existing in ECOSSE. However, this would require data describing the soil characteristics under the different land use classes to be divided into the same land classifications as used in IACS, which is unlikely to be feasible given the current availability of soil data.

Using IACS data in place of CS or LULUCF data increases the spatial resolution of simulations from 20km to 100m grid, an increase in spatial resolution by a factor of 40,000. In addition, the annual update of IACS data has the potential to increase the temporal resolution from decadal to annual, an increase in temporal resolution by a factor of 10. If a suitable year since 2000 can be used as the baseline for land use change data from IACS and a method for relating this back to 1990 (the date the inventory for GHG emissions uses as a baseline) then it would be better to use this rather than the current method.

Over the long term, the ECOSSE model for soil carbon stock change produces similar results to the CFlow model used in the current inventory, but the dynamics of the simulations differ due to the detail of turnover processes included in ECOSSE. An earlier Scottish Government funded project (Smith et al, 2009) used National Soils Inventory data to estimate the uncertainty in the simulations of soil carbon stock change provided by ECOSSE to be 11%. As more soils data and information becomes available for Scotland the estimates of uncertainty in ECOSSE will be reduced.

An annual GHG emissions inventory for the land use sector in Scotland would be greatly improved in its accuracy by using IACS data if it can be linked to a 1990 baseline. In time a more realistic estimate of C losses and gains from land can be obtained using the ECOSSE model to simulate the response of organic and organo-mineral soil types to land use change especially once more underlying soils information for currently underrepresented land use categories such as forestry and semi-natural become available.

2. Background

The Intergovernmental Panel on Climate Change (IPCC) reporting obligations require annual data for greenhouse gas (GHG) emissions from land use, land use change and forestry (LULUCF) sectors from participating countries. In addition to international obligations for the UK, the Climate Change (Scotland) Act 2009 requires reporting of emissions data at a country level on an annual basis. Given the significant contribution estimated for the land use (LU) sector to Scotland's emissions (15%), and the uncertainty surrounding this figure, this pilot study provides a useful analysis of a different approach to deriving land use change (LUC) emissions for Scotland.

Scotland's soils are carbon rich (estimated to contain 11,000 $MtCO_2$ equivalents – Smith et al., 2007) and are potentially a large source of GHG emissions when subject to LUC and climate change. The current methodology employed by CEH for the UK GHG Inventory for LULUCF use data is derived from the Countryside Survey, which is undertaken approximately every 10 years, and Forestry Commission data, which is mostly updated annually. Carbon fluxes from soils are determined using the CFlow model for the Forest Land category and a dynamic land use-soil carbon model for the other LU categories. In a new approach, the Scottish Government (SG) along with the Welsh Assembly Government co-funded the ECOSSE model (2007) to simulate the response of carbon-rich soils to LUC and climate change (http://www.scotland.gov.uk/Publications/2007/03/16170508/0). The ECOSSE simulations were limited to data derived from the Countryside Survey.

This project seeks to evaluate the use of annual IACS data for LUC in the Scottish agricultural sector alongside a model (ECOSSE) to simulate carbon sources and sinks from soils and vegetation associated with these changes. The project compares the outputs from ECOSSE with the current CEH GHG Inventory produced for Scotland.

For forestry and semi-natural LU categories, an exploration of how LUC data can be derived from alternative sources to the Countryside Survey has been undertaken. A review of underlying soils data which is used in the emissions inventory for non-agricultural LU categories has been completed, and recommendations as to how this may be improved are given.

2.1 Aims

The aims of the project are

- To produce an agricultural LUC inventory for Scotland using annual IACS data held by the SG and the ECOSSE model to simulate changes in soil and vegetation C stocks as a result of these observed LUCs.
- To compare and contrast the results with the current inventory, highlighting the strengths and weaknesses of both approaches, and provide a commentary on those results
- To critically assess the current LULUCF inventory and how underlying soils data for LU categories important for Scotland such as semi-natural and forestry could be better represented.
- Provide a clear analysis and guidance on the implications of different methods and approaches in producing an assessment of agricultural LUC and a GHG emissions inventory for Scotland on an annual basis.

2.2 Land use change data used in the current CEH GHG Inventory

Reporting in the LULUCF inventory, in accordance with IPCC good practice guidance (IPCC 2003), is based on broad land categories: Forest Land, Cropland, Grassland, Wetlands, Settlements and Other

Land. All land areas within a country should be assigned to one of these categories. UK definitions of these land use categories are given below:

- Forest Land: land under stands of trees with a canopy cover of at least 20% (or having the potential to achieve this), including integral open space, and including felled areas that are awaiting restocking. There is no minimum size for a woodland.
- Cropland: All arable crops, orchards, market gardening and commercial flower growing. Freshly ploughed land, fallow areas, short-term set-aside and annual grass leys are also included in this category.
- Grassland: Land that is not Forest Land or Cropland where grazing is the pre-dominant land use.
- Wetlands: The IPCC (2006) definition of Wetlands is any land that is covered or saturated by water for all or part of the year, and that does not fall into the Forest Land, Cropland, or Grassland categories. In the UK, saturated land (based on the Countryside Survey Broad Habitat classification) such as bogs or marshes will fall into the Grassland category (as it is principally managed for grazing). Land covered by open water (e.g. lakes, rivers, reservoirs) is included in the Other Land category.
- Settlements: land covered by urban or rural settlement and other man-made built structures, waste and derelict ground, transport infrastructure, parkland and gardens.
- Other Land: this includes all land not included under the other categories.

The correspondence between these definitions and land definitions used by data sources (Monitoring Landscape Change, Countryside Survey) is described in the UK's National Inventory Report (MacCarthy et al. 2010).

The UK compiles different data sources into a non-spatially-explicit land use conversion matrix for inventory reporting (IPCC Approach 2). The data sources are available at the individual country level (England, Scotland, Wales and Northern Ireland). Decadal matrices of land use change from 1950 (table 2.1) have been developed from the Monitoring Landscape Change project dataset (using a sample survey of aerial photographs in 1947 and 1980) (MLC 1986) and the ITE/CEH Countryside Surveys of 1984, 1990 and 1998 (Barr *et al*. 1993; Haines-Young *et al*. 2000; Cooper and McCann 2002), which are based on repeated sample field surveys. A new Countryside Survey was undertaken in 2007 (Carey *et al*. 2008; Cooper *et al*. 2009) but the detailed data are still being assimilated into the inventory.

Table 2.1 Sources of land use change data in Great Britain for different periods used to estimate 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 - 2008	*Extrapolated*	CS1990->CS1998

These data are supplemented by areas of land use change to Forest (afforestation) coming directly from planting data provided by the Forestry Commission. The allocation of Forest land use change between Cropland, Grassland and Settlement is based on the proportional changes in the land use change matrices from the Countryside Survey (but we do not use the areas for conversion to forest from these matrices), At present, published forest statistics make no adjustment for woodland converted to another land use (i.e. deforestation). Areas of land use change from Forest to Grassland come from Forestry Commission data on unconditional felling (principally heathland restoration to Grassland). Areas of converted land for all of Great Britain are extrapolated from the English data for 1990-2002 (based on the 1999-2001 ratios for Great Britain). No recent data has been collected so rates of conversion for 2003-2008 are extrapolated. Activity data on areas of Forest Land converted to Settlement are extrapolated from data for England held by the Department of Communities and Local Government (DCLG). They obtain this information from the Ordnance Survey (the national mapping agency) which makes an annual assessment of land use change from the data it collects for map updating. Areas of Forest Land conversion to Settlement are calculated as the sum of all forest land use categories to urban land use categories. (Note that this data set is not thought to be reliable for forest conversion in rural areas because the resurveying frequency is too low).

Land use change matrices are compiled and used at the individual country level for the purposes of national CEH GHG Inventory reporting. Estimates of land use change at the 20km scale are used for mapping of LULUCF emissions and removals (Hallsworth and Thomson 2010). Case studies of land use matrix development for Scotland and Wales are described in the ECOSSE report (Smith *et al*. 2007), and the same approach has been used to develop matrices for England and Wales.

2.3 IACS Data

IACS is the Integrated Accounting and Control System maintained by the Rural Payments and Inspection Directorate (RPID) of Scottish Government. Since 1994 this database has supported a wide range of RPID functions most notably the calculation and payment of farm subsidies.

In the context of this project the key IACS data tables are those recording land use(s) for each field. This land use data is recorded per field in the Field Data (FD) tables. Field boundary maps are also maintained as part of a rolling programme of updates to the Field Information System (FIS) (also referred to as the Field Register (FR)). Each field in the geographical information system (GIS) map has a field id (FID) that links to entries in the FD tables to give a spatially explicit map of land use (figure 2.1).

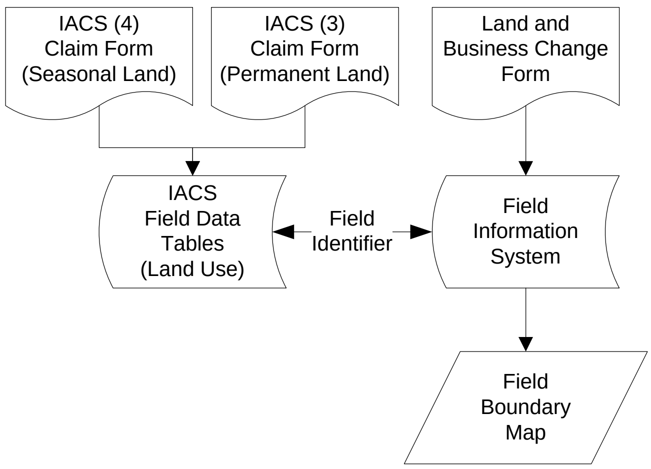

Figure 2.1 IACS land use and field data

2.3.1 Data Sources

Land use information in the FD tables is derived from land managers submitting claims for support schemes such as the Single Farm Payment (SFP), Less Favoured Area Support Scheme (LFASS) and Scottish Rural Development Programme (SRDP). Data is returned both from Permanent Land (i.e. land that is owned and used) and Seasonal Land (i.e. land that is rented in). There is a May 15th deadline for submission of IACS forms with the window for submissions opening in early spring. All claims are subject to quality control processes with 95% of data processing completed by December of the claim year. Updates to the FIS/FR are based on Land and Business Change Forms (LBCF) submitted on change of ownership or revision of field boundaries (merging, splitting or realigning).

2.3.2 Classification

The data recorded in IACS under land use is a mix of land use and land cover (see Appendix 1). For cropping, use and cover can be synonymous (or is distinguished by codes identifying fodder or non-food crops). For grassland a specific land use requires the use of supplementary data usually on livestock. The notable exception to this classification is rough grazing where the use is recorded but not the specific nature of the cover being grazed. In this case the land use is assumed to be semi-natural pastures. The classes of land use recorded have varied over time, reflecting the requirements of specific payment schemes. Since 2009 IACS returns have also been used as part of fulfilling of the statistical requirements of the June Agricultural Census. This means that going forward there will be greater continuity of classification to support trend analysis.

2.3.3 Coverage

From 2000 to 2009 coverage with (recorded land uses) has increased from 4.4 million ha to 5.7 million ha (see figure 2.2). This reflects the wider range of businesses submitting claims recently, for example, for SRDP (see figure 2.3). Coverage is most complete in the lowlands and the south and east of Scotland. Where particular land based activities have not attracted subsidy in the past (e.g. sporting estates and some forms of horticulture) then these businesses tend not to appear in the mapping. Woodland is also under represented in the IACS mapping. Figure 2.4 shows the coverage of IACS fields with known land use in 2009. It should be noted that while land use records exist between 1994 and 1999 (2.1 million to 4.1 million ha), these are not spatially explicit since there are no associated maps of field boundaries prior to 2000.

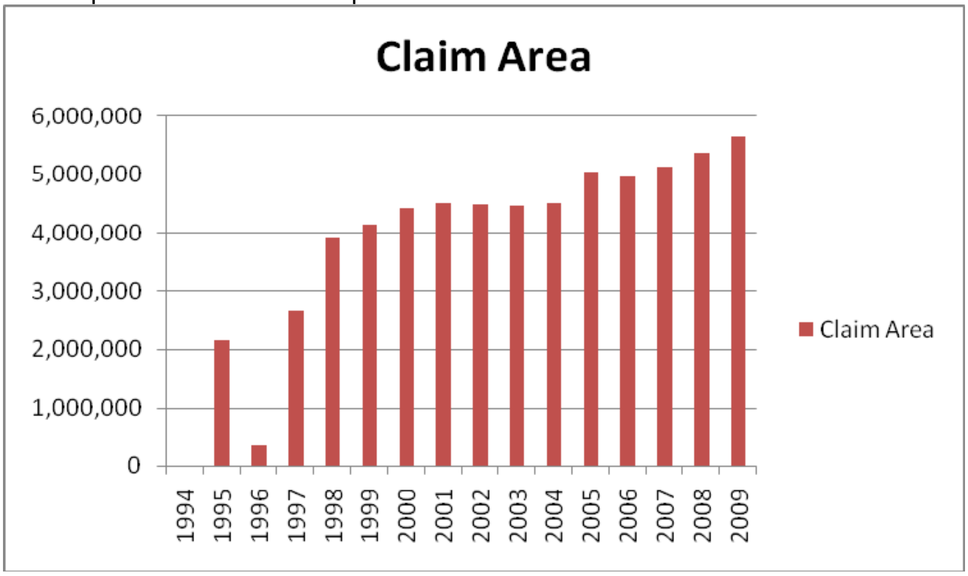

Figure 2.2 IACS claim areas 1994-2009

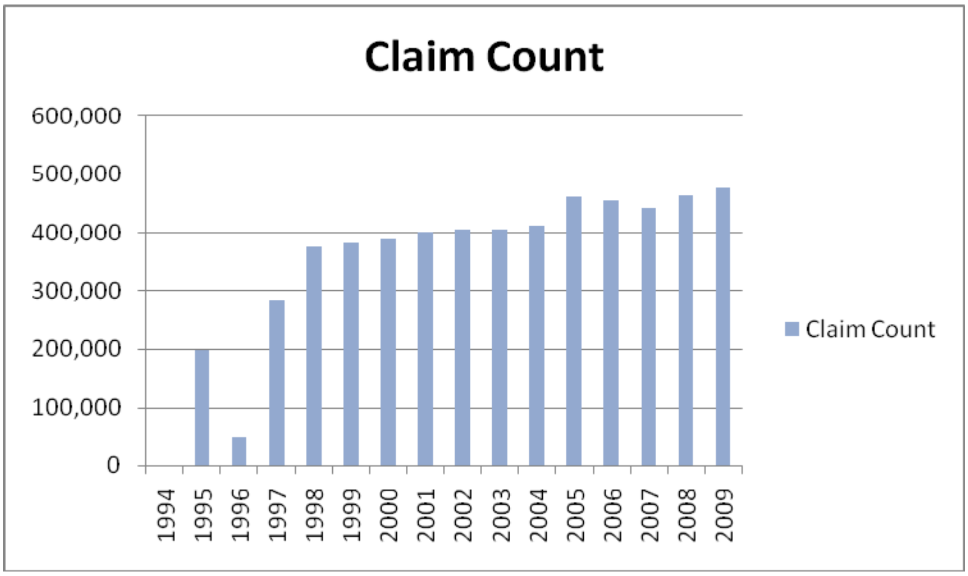

Figure 2.3 Count of IACS claims for land parcels 1994-2009

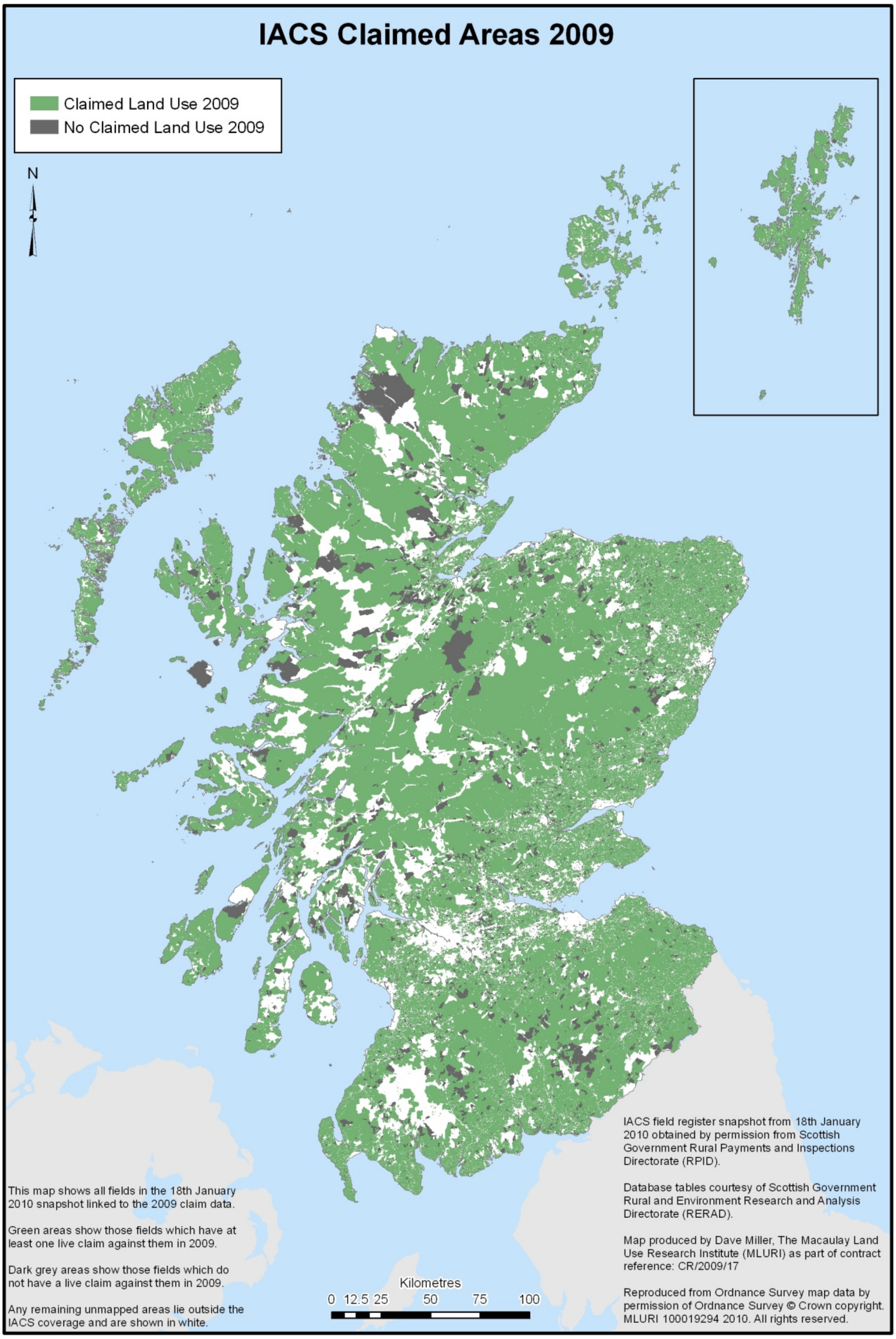

Figure 2.4 IACS 2009 coverage

2.4 The ECOSSE spell out ECOSSE here? Model

Given the importance of soil carbon (C) in Scotland, it is important that we gain more reliable estimates of changes in soil C stocks. The recently completed ECOSSE project highlighted the uncertainties in our knowledge in this area (Smith et al., 2007a,b). This project has allowed us to further develop and improve the ECOSSE model, quantifying and reducing the uncertainty of the estimates of C stocks in Scottish soils. The Scottish Executive and Welsh Assembly Government funded the development of the ECOSSE model in 2004 to predict the response of mineral and organic soils to both LU and climate change.

Whilst a few models have been developed to describe deep peat formation and soil organic matter turnover, before ECOSSE was constructed, none had been developed that were able to examine the impacts of land-use and climate change on the types of organo-mineral soils often subject to land-use change in Scotland and Wales. The organo-mineral soils (e.g. peaty podzols and peaty gleys) subject to land-use change are characterised by a shallower organic horizon than true peats.. The main aim of ECOSSE was to simulate the impacts of land-use and climate change in these types of soils as well as in mineral and more highly organic soils (defined as peat). Driven by commonly available meteorological data and soil descriptions, the model predicts the impacts of land-use change and climate change on C and N stores in organic soils in Scotland and Wales.

ECOSSE uses a pool type approach, describing soil organic matter as pools of inert organic matter, humus, biomass, resistant plant material and decomposable plant material (figure 2.5). Material is exchanged between these pools according to first order rate equations, characterised by a specific rate constant for each pool, and modified according to rate modifiers dependent on temperature, moisture and pH of the soil. The N content of the soil follows the decomposition of the soil organic matter (figure 2.6), with a stable C:N ratio defined for each pool at a given pH, and N being either mineralised or immobilised to maintain that ratio. Mineral N may then be lost from the soil by the processes of leaching, denitrification, volatilisation or crop off take, or C and N may be returned to the soil by plant inputs or organic amendments. The soil is divided into 5 cm layers, so as to facilitate the accurate simulation of these processes down the soil profile. Each of the processes included in the model is simulated using only simple equations driven by readily available inputs, allowing it to be developed from a field based model to a national scale tool, without a high loss of accuracy.

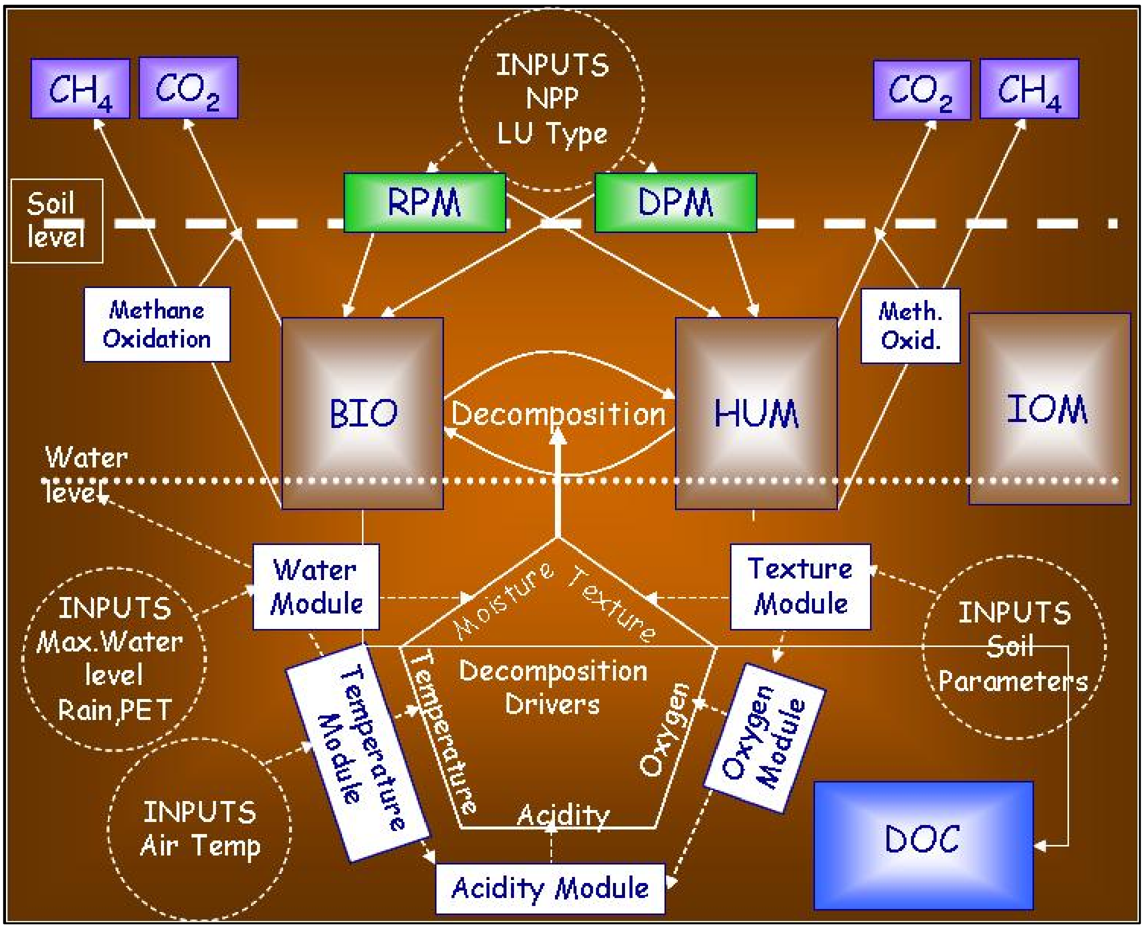

Figure 2.5 Structure of the carbon components of ECOSSE

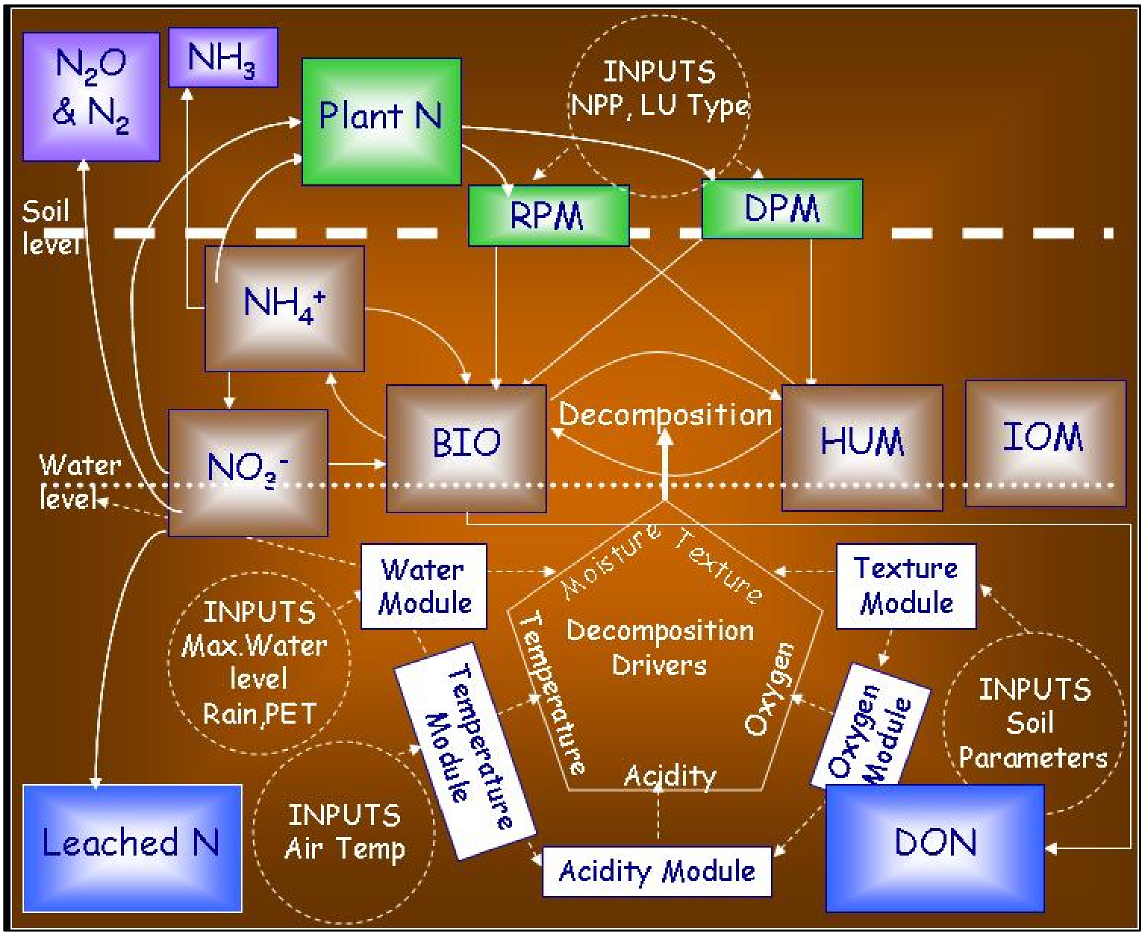

Figure 2.6 Structure of the nitrogen components of ECOSSE

2.5 The current CEH GHG Inventory for Scotland

The most recent CEH GHG Inventory for Scotland (Sneddon et al. 2010) estimated Scotland's LULUCF sector to be a net sink of -4.48 Mt CO_2 in 2008. Net emissions/removals in Scotland are dominated by the large Forest Land sink (-9.16 Mt CO_2 in 2008), although the Cropland source is also significant at 6.64 Mt CO_2. The Grassland and Settlement fluxes were smaller (-2.73 and 1.68 Mt CO_2 respectively). The majority of these emissions/removals arise from soil carbon changes as a result of land use change between categories. These figures compare to the total GHG emissions in Scotland of 53.7 Mt CO_2 e in 2008.

The methods for estimating emissions and removals of greenhouse gases from this sector, data sources and underlying assumptions are described in the latest UK national inventory report for 1990-2008 (MacCarthy *et al*., 2010). The current LULUCF inventory methods use a combination of top-down and bottom-up approaches, based on activity data for each of the Devolved Administrations (DAs) and the UK as a whole. As a result of this approach, estimates of emissions and removals from LULUCF activities are automatically produced at the DA and UK scale.

2.6 Approach

This pilot inventory has been undertaken in three phases.

Phase 1 focuses on the Integrated Administration and Control System (IACS) data and provides an in depth analysis of the content, coverage and availability of the data included in the IACS forms, with respect to the data required for the GHG inventory and to drive the ECOSSE model.

Phase 2 focuses on the modelling methodology required for using the IACS data in ECOSSE and the CEH GHG Inventory.

Phase 3 focuses on the availability of soils data, particularly for the LU categories semi-natural and forestry.

3. Use of IACS data in the CEH GHG Inventory and ECOSSE

Phase 1 focuses on the IACS data and provides an in depth analysis of the content, coverage and availability of the data included in the IACS forms, with respect to the data required for the CEH GHG Inventory and to drive the ECOSSE model. Factors addressed include the translation of LU categories between the IACS database and the models, the use of spatial information, the description of LUC, use of land management data and integration of spatial forestry and IACS datasets.

3.1 Translation of land use categories

Due to time constraints in this short 3 month project, the database needed to drive the models has been derived from the IACS data by translating the IACS LU categories into the existing model LU types. The alternative approach, to develop LU types in the models that correspond to the IACS categories, would require more time than is available on this project.

The translation of IACS data classes into categories that can be used by the models is given in appendix 1.

3.2 Generating the inputs for the CEH GHG Inventory and ECOSSE

3.2.1 Existing Approach – combining land use change with soils at 1km resolution

For each 1km square a matrix of LUC and a list of soils were generated separately. Since it was not certain on which soil the LUC occurred, the LUC was disaggregated proportionally across all soils present. The lack of specificity in terms of which LUC occurred on a particular soil introduced uncertainty into the outputs from both models. It may also have added an unquantified bias to the results since errors may not have been compensating. Operationally this approach also has the disadvantage of generating the maximum number of combinations of soils and LUC possible, so increasing the computer time required to complete a calculation. Since each combination requires an ECOSSE or Inventory model run the matrix-based approach has a significant processing overhead.

3.2.2 Outline of the new approach – identifying unique combinations

The alternative approach tested here does not summarise (with non-spatial matrices) at a single compromise resolution (1km grid). Instead all datasets are used at their best feasible resolution (LUC between 2000 and 2009 and soils at 100m grid, climate/CC at 5km grid and historic decadal LUC (1950-1990) at 20km grid). Using these datasets together it is possible to identify all of the unique combinations of LUC, soils, climate and decadal change that occur. This unique combinations procedure is illustrated in figure 3.1). At a conceptual level the process generates:

1) a table of unique combinations and
2) a map of where those combinations occur.

Each line of the table (when linked to other datasets, see below) provides all the inputs required for a single run of the CEH GHG Inventory and ECOSSE. The results from the CEH GHG Inventory and ECOSSE can be added to the row of the table (for later summary) and also mapped by adding the model results data to the relevant cells in the unique combinations map.

The unique combinations approach retains the best spatial resolution for high resolution datasets (LUC and Soils at 100m grid). This means small changes can still be detected and these are now more closely tied to specific locations and circumstances. Running the models, however, remains computationally feasible since the number of unique combinations (93,228) even with LUC and soils at 100m grid, climate at 5km grid and decadal LUC at 20km grid resolution is significantly less than the number of cells in the highest resolution dataset (7,880,970[1] for 100m grid) and is only marginally more than even the number of cells in the previous 1km grid summary dataset (a maximum of 85,405[2]). The previous 1km resolution datasets would in any case have to be run for all combinations of LUCs and soils present in each cell. This means that the unique combinations dataset has less uncertainty in terms of combinations of LUC and soils, is spatially more explicit and requires less computational time to complete calculations for ECOSSE or the CEH GHG Inventory.

3.2.3 Detail of how the Unique Combinations dataset was generated

Figure 3.1 illustrates the process used for generating the input datasets for the CEH GHG Inventory and ECOSSE.

Each of the input datasets is identified (A-G) and tabulated in table 3.1 with the key data processing stages of processing identified (1-7) and keyed in the explanatory text below).

Table 3.1 Input datasets used to generate all unique combinations

Id	Dataset	Source	Scale/Resolution/Format
A	Land Use, 2000	RPID	Map and Database, 1:10,000, vector, field boundaries
B	Land Use, 2009		
C	Soil Map	MLURI	Map, 1:250,000, vector, soil map units.
D	Current (1960-2010) and Future (2011-2019) Climate	Met Office	Map and Database, 5km grid
E	Decadal Land Use Change (1950 to 1990)	CEH	Map and Database, 20km grid,
F	Soil Series per Map Unit	MLURI	Database Table
G	Soil Physical and Chemical Properties	MLURI	Database Table

(0) Cross checking of land use data

Before undertaking analysis, the raw data submitted by land managers need to be cross checked to ensure consistency. This is undertaken within RPID but the results are not stored in a form compatible with this analysis. Simple cross checking of claimed and field boundary areas is possible for all years and from 2009 it is possible to cross check land rented in from the IACS(4) Seasonal Land form against IACS(3) Permanent Land form. Appropriate strategies of resolving data quality issues have been tested and found effective for other IACS based projects.

(1) Predominant land use

The predominant land use for each field in both the 2000 and 2009 datasets is determined on a simple majority or plurality basis using the claim areas (from the database). This land use is used for the whole of the mapped polygon. The justification and consequences of this simplifying assumption are discussed in detail in the caveats to the analysis in section 3.2.4.

(2) Vector-raster conversion

The vector raster conversion takes the field outlines and the soils polygons and converts each into a grid. The cells in each of the IACS LU raster maps hold the predominant LU and the cells in the

[1] 100m cells in the raster conversion of the Scottish Coastline down to the Mean High Water Mark as represented in OS MasterMap.
[2] 1km cells which intersect the boundary of the Scottish Coastline down to the Mean High Water Mark as represented in OS MasterMap.

1:250,000 soils raster map holds the map unit[3]. The resolution of these raster datasets were set at 100m to give a cell size and maximum reportable accuracy of 1ha. For a national scale analysis this was seen as adequate for defining the minimum detectable LUC and 100m was the limit of resolution compatible with the scale of the soils mapping. The vector raster conversion was implemented in Arc-Info GIS[4] using standard routines.

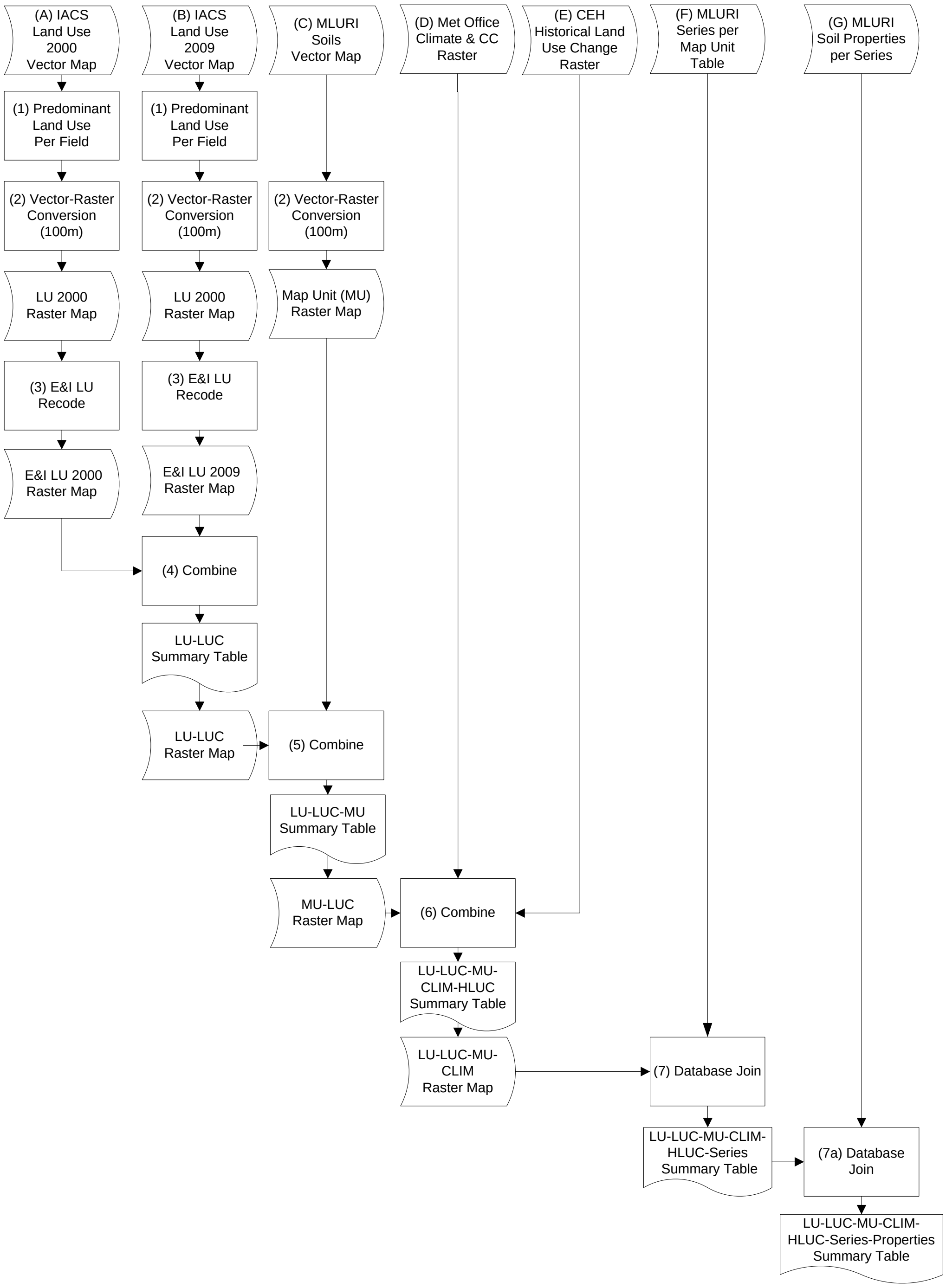

Figure 3.1 Schematic of the data integration to derive the inputs for ECOSSE and the CEH GHG Inventory

[3] The map units of the 1:250,000 scale soil map are based on recurrent landform patterns and component soils. Differing parent materials sub-divide these recurrent patterns.
[4] Ref to ArcInfo vector raster.

(3) Recoding or simplifying IACS derived land use data

The ECOSSE model and CEH GHG Inventory are currently parameterised to account for changes between four types of LU; cropping (including improved pasture), grassland, forestry and semi-natural. The more complex IACS LU classification can thus be simplified by a process of recoding. A look up table was generated for all LU classes present across all years of IACS data mapping[5], with each IACS class mapped onto an ECOSSE and CEH GHG Inventory (E&I) class. The generation of the look up tables was undertaken by both the ECOSSE and CEH GHG Inventory teams with a second iteration undertaken when there was initial disagreement between the two teams. The full list of IACS LUs and their E&I class equivalents were agreed after the 2 iterations and are presented in appendix 1. The look-up tables were used in a field-calculator expression[6] within Arc-Info GIS to create a new raster map of E&I classes.

It should also be noted that the IACS LU classification has changed over time, reflecting its primary function of supporting payments schemes. Since 2009, however, IACS data has also been used as a basis for the partial fulfilment of the statistical data requirements of the June Agricultural Census (JAC)[7]. This means that there will be more continuity in terms of the classes present, particularly given the need for JAC to maintain continuity of classification to support trend analysis.

(4) Generating the land use and land use change datasets

Both LU and LUC data are required to run ECOSSE and the CEH GHG Inventory. Land use change data was generated by combining the raster IACS LU 2000 and the IACS LU 2009 datasets. The Arc-Info GIS "combine" routine[8] generates a list of all the unique combinations of data in the two input datasets and a map of where each of those combinations occurs[9]. Table 3.2 illustrates a coding where all combinations of E&I classes are present. Of the 16 combinations, 12 are change and 4 (the diagonal, numbers 1, 6, 11 and 16) no change. The output table from the combination routine also holds a count of the number of times a combination occurs and since each cell is 1ha the count is, in effect, a summary of the area of each LUC (table 3.3).

Note also that since the coverage of IACS has increased from 2000 to 2009 there are unmapped areas in 2000 for which mapping and/or LU data are available in 2009. Also note that there are IACS fields for which there is no known LU. These are businesses where no claim for payments has been made but they have been mapped as part of other RPID processes. These unmapped and unknown LUs do add additional combinations to the LUC table (for a total number of unique combinations of 30). These unmapped or unknown combinations can be excluded from the analysis since LUC by definition can only be determined where there is LU data in both datasets. In an annual implementation of the analysis, the unmapped area (and thus total coverage) would be limited only to the area of the previous year rather than to coverage from ten years previously as in the example case[10].

Implementation difficulties associated with derivation of land use change data are illustrated for a sample area in appendix 2.

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[5] This look up table is thus suitable for use with any IACS data not just the 2000 and 2009 years used in this feasibility study.
[6] Ref to ArcInfo
[7] http://www.scotland.gov.uk/Publications/2008/08/06104732/0
[8] Ref to ArcInfo combine
[9] Each cell of the map contains one of the codes in the table of unique combinations.
[10] The decadal separation of dates was chosen to allow direct comparison with existing ECOSSE and GHG Inventory analysis.

Table 3.2 Land use change codes used during generation of the land use change dataset

Land use change codes	Land Use 2009			
Land Use 2000	Cropping	Grassland	Woodland	Semi-Natural
Cropping	1	2	3	4
Grassland	5	6	7	8
Woodland	9	10	11	12
Semi-Natural	13	14	15	16

Table 3.3 Matrix of LUC 2000-2009

Area (ha)	2009 →					
2000 ↓	Cropping	Forestry	Grassland	Other	Semi-Natural	2000 Totals
Cropping	891,594	5,317	115,821	1,478	6,914	1,021,124
Forestry	241	7,750	508	110	1,587	10,196
Grassland	78,567	13,434	654,498	1,331	352,235	1,100,065
Other	15,265	17,007	4,248	3,737	36,049	76,306
Semi-Natural	5,732	33,586	88,193	677	2,181,460	2,309,648
2009 Totals	991,399	77,094	863,268	7,333	2,578,245	4,517,339
Net change	- 29,725	66,898	- 236,797	- 68,973	**268,597**	
No Change					3,739,039	

(5) Generating land use change - soils data

The soil on which LUC occurs is a key factor in estimating the consequences of change. Soil map units (MU) are the spatially explicit representation of soil properties. The raster map of soil MU (figure 3.3) is combined with the map of LUC (figure 3.2), again using the "combine" routine in Arc-Info GIS. Since there are many more MU's (580) being combined with the 30 LUCs the number of unique combination that results is larger at 6,711, but only 38% of the 17,400 possible combinations. This indicates a degree of correlation between groups of land use changes and soils (as represented by the MUs).

(6) Adding climate and decadal land use change

ECOSSE also requires climate and climate change (CC) data and both models require previous decadal scale LUC data. As with soil map units it is only necessary to add an identifier (grid cell id) as a link from the LUC-Soils table/map to a row in the tables of climate data values and/or decadal LUC values. Each 5km grid cell (for climate/CC, figure 3.4) or 20km grid cell (for past LUC, figure 3.5) has a unique combination of data values so there are 3492 x 5km grid cells and 330 x 20km grid cells. The 5km grid cells use the same origin and thus nest within the 20km grid cells (4 x 4). The cell ids are added to the LUC-Soils table/map using the same combining rasters approach detailed above. Despite only adding 3500 cells, as each climate cell is unique, the number of combinations increases substantially to 93,228. Note that in the 5km grid climate/CC dataset there is not complete coverage of all land in Scotland. Cells where land makes up less than ~50% of the 5km grid cell can be omitted (area of land affected is 79,198[11] ha).

[11] Cells are part of the soils map unit layer but are not part of the climate 5km layer.

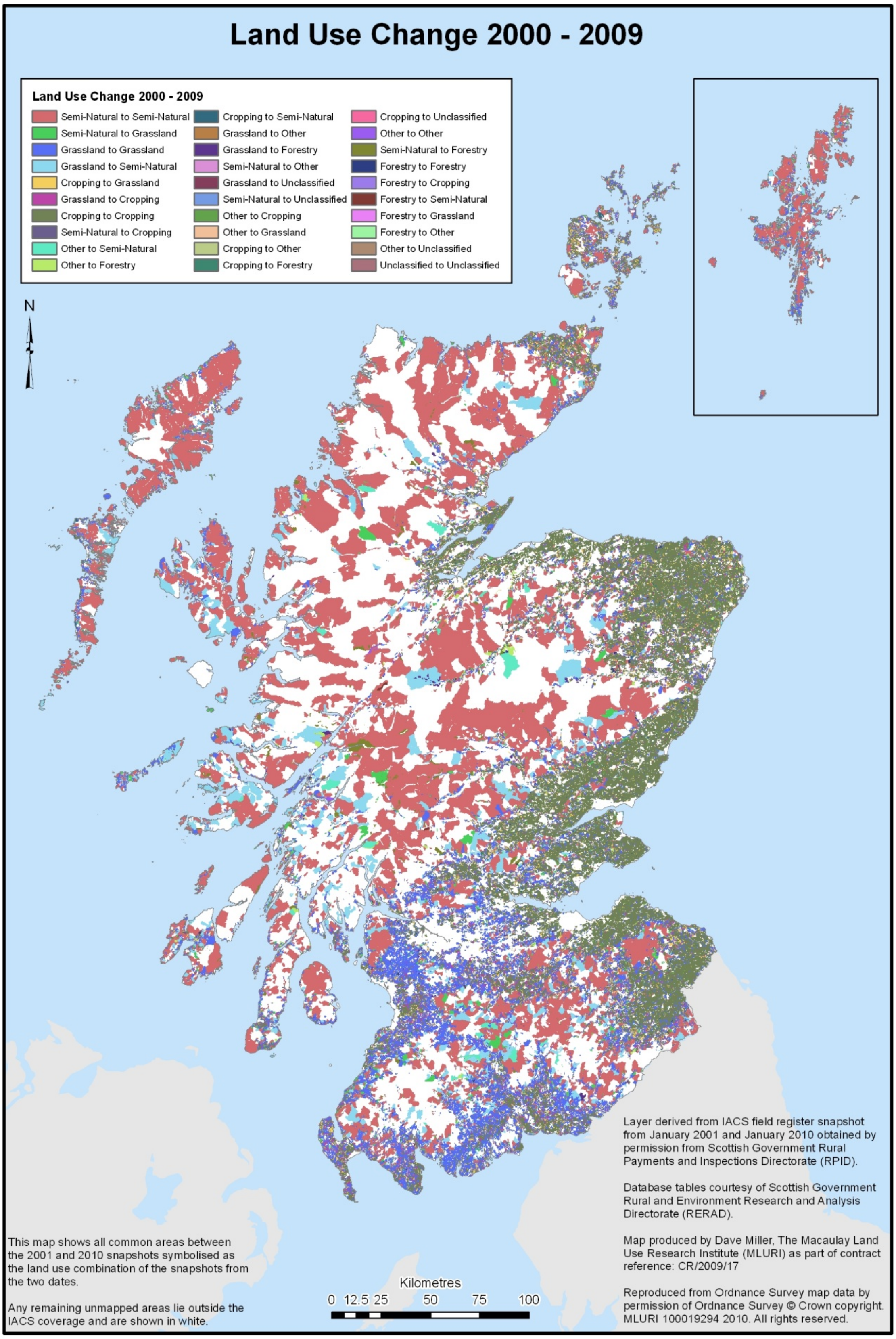

Figure 3.2 Land use change across Scotland between 2000-2009 as specified by IACS data

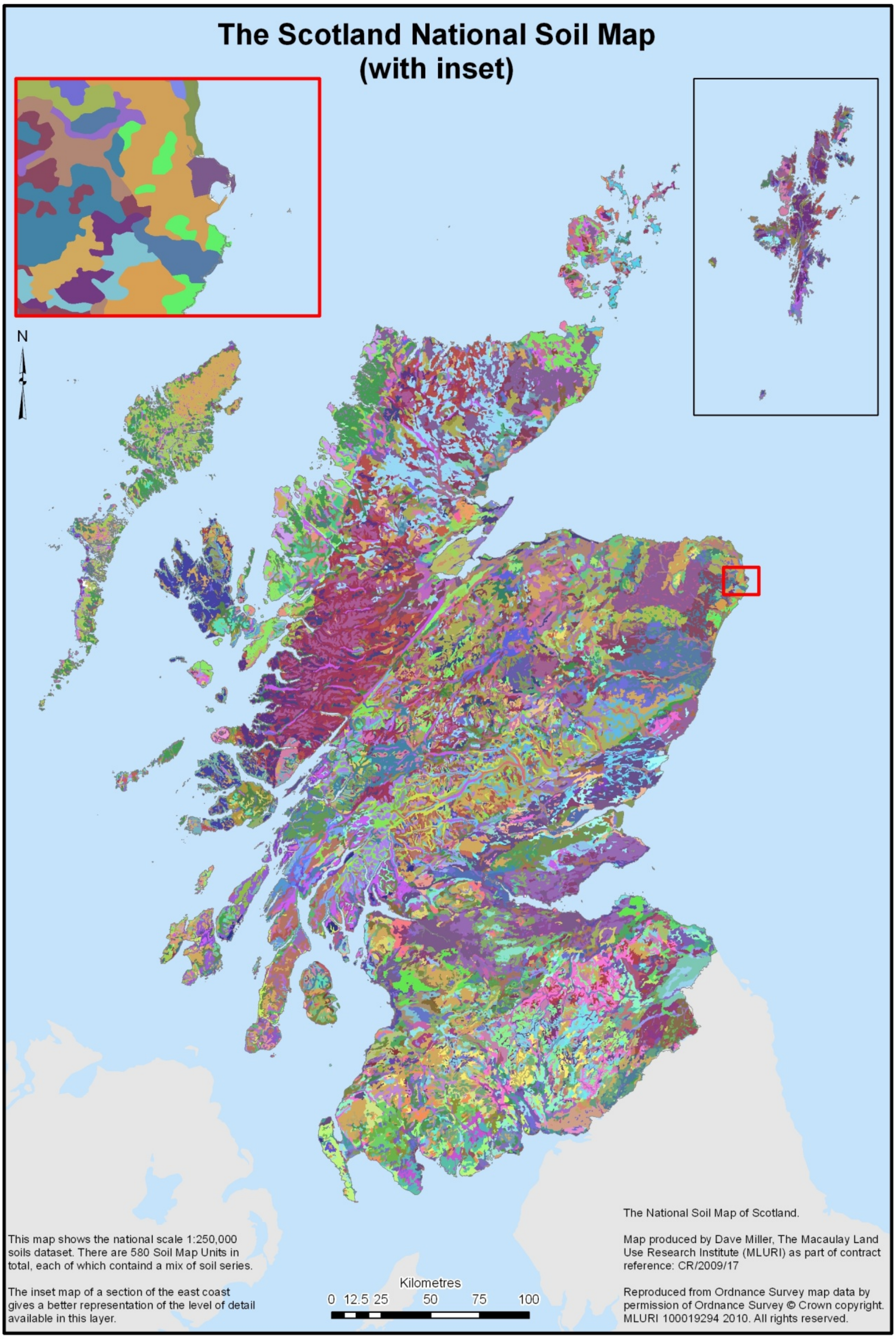

Figure 3.3 Soil map units – the map is included as an illustration only of the map units spatial heterogeneity not to allow the identification of specific units. Thus no legend is provided and the map units are coloured randomly.

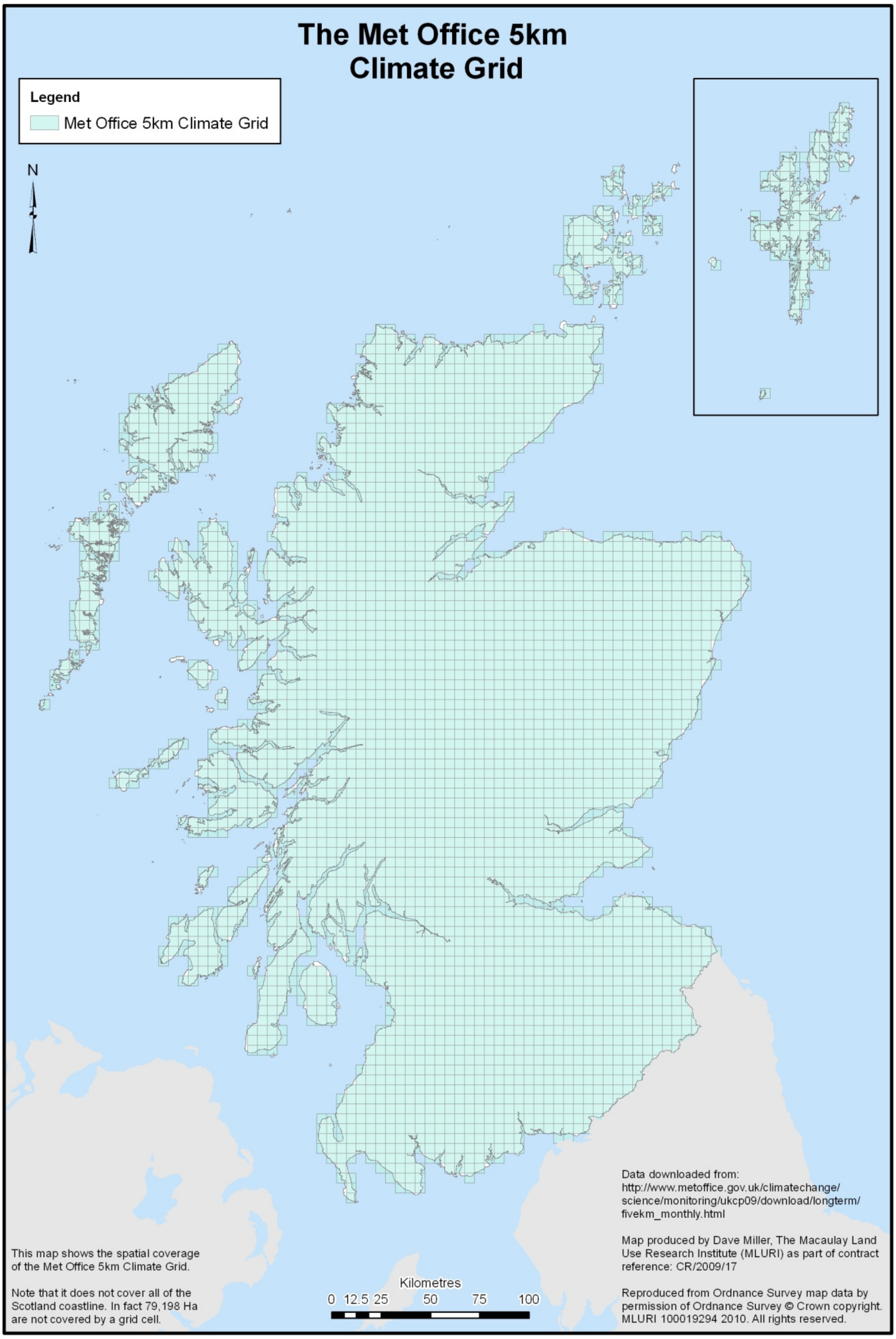

Figure 3.4 Met Office 5km grid

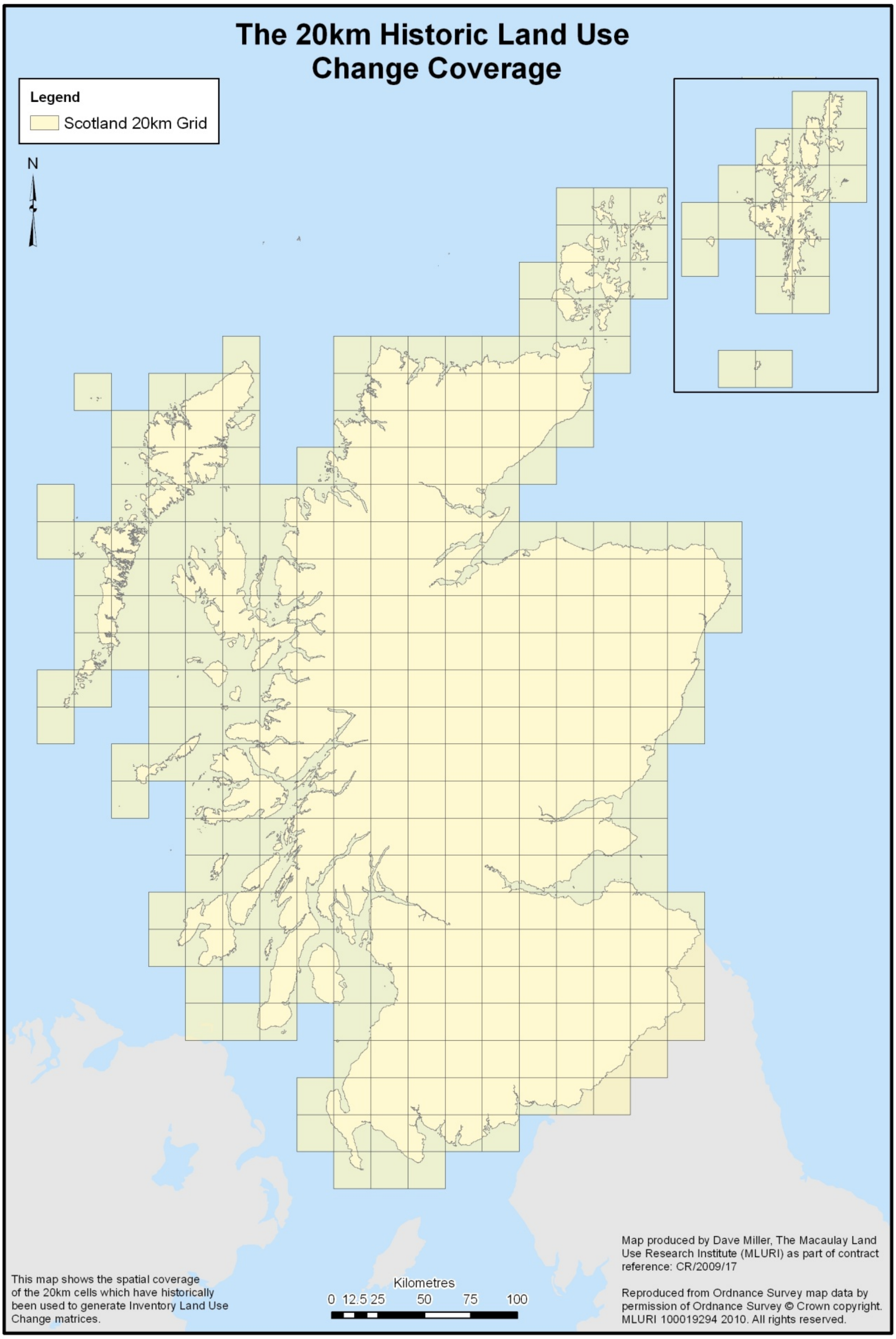

Figure 3.5 Historic Land Use Change Grid.

Figure 3.6 Example of mismatch in coverage between 5km climate and 100m soils map grid cells.

(7) Adding soil physical and chemical properties

The spatial representation of soils data included in the LU - LUC - MU - climate (CLIM) - historic land use change (HLUC) table/map is the Map Unit. The soil physical and chemical properties required by ECOSSE and the CEH GHG Inventory are, however, summarised at the Soil Series level. Soil Map Units are made up of one or more Soil Series with estimated proportions. Since the Series may have significantly different properties it is necessary to disaggregate the LUC associated with a soil map unit across the component series. This means that for every unique combination where the map unit has more than one series, additional rows are added to the LU-LUC-MU-CLIM-HLUC table. This creates a LU-LUC-MU-CLIM-HLUC-Series table.

Appropriate series summary data can then be added or linked to the LU-LUC-MU-CLIM-HLUC-Series table. The series summary data is currently differentiated into cultivated and uncultivated with the choice based on the LU data. The final table with all data needed to run the E&I models is the LU-LUC-MU-CLIM-HLUC-Series-Properties table. This table has 157,853 entries and is the number of times ECOSSE has to be run (since CEH GHG Inventory does not make use of the climate datasets the number of unique combinations for the CEH GHG Inventory is only is 11,068).

3.2.4 Caveats to the analysis

Multiple land uses per field

The calculation of predominant LU in the vector-raster conversion process can be compromised if particular combinations of multiple LUs are present. Consider the following example with three IACS LUs, 34% trees, 33% barley and 33% wheat. The simple predominant LU for IACS is trees but when taken together the barley and wheat areas (the same E&I class) are 66%. This type of issue potentially arises in only a minority of cases, only 11% of fields or 12% of area in 2009 IACS mapped land have more than three LUs present. In an operational system it would be preferable to recode the IACS LUs before undertaking the vector raster conversion process. This ensures that in a field with more than two E&I classes, the correct predominant E&I class is always determined.

Even undertaking recoding first, however, there remain issues with the simplifying assumption of using predominant LU. The thresholds inherent in using predominant LU have the potential to either exaggerate or hide changes that occur within map units with multiple LUs present but not spatially explicit. For example with 49% forestry to 51% semi-natural, a change of only -2% in semi-natural would result in the whole field classification changing from semi-natural to forestry. Since the predominant LU is applied to all of the mapped area the area of apparent change can be exaggerated. Conversely a large percentage change in LU (e.g. 99% to 51%) could not alter the predominant E&I LU and change would thus be under reported. Thresholds combined with variable sized units means that it is not a simple matter to be certain what the minimum detectable change is. Neither of these effects is particularly significant when the areas of the individual mapped unit are small relative to the scale at which results are reported. In some cases, however, there are very large IACS mapped units that contain different E&I classes and it is in these cases where consideration should perhaps be given to subdividing the units[12], or at a minimum ensuring that multiple E&I classes are not combined in the same map unit.

Table 3.4 provides a break down by E&I class of the area of over estimation caused

1) by the use of a predominant land use class and
2) by applying the predominant claimed land use to all the map polygon area (extrapolation).

Note that these figures use the full 2009 coverage. It can be seen that the magnitude of the errors introduced by the use of predominance is relatively small, 128,701 ha, ~2% of the IACS mapped area for which land use is known. It is, however, seen to be applied disproportionately to the forestry class. The magnitude of the extrapolation used when the polygon area is larger than the sum of all claims is more significant at 281,359 ha and the validity of the extrapolations may need to be considered

[12] Perhaps with a maximum size in ha.

further. The overall area subject to both these reservations is, however, ~8% of the total IACS mapped area, with the worst affected class being semi-natural.

Table 3.4 Estimates of error introduced by LU dataset processes (ha)

	Cropping	Grassland	Forestry	Semi-natural	Other	All LU
Predominance	18,999	28,889	6,764	73,721	329	128,701
Extrapolation	7,356	17,363	10,053	246,529	58	281,359
All Errors	26,355	46,252	16,817	320,250	387	410,061
Area 2009	980,769	895,977	420,492	3,122,701	11,180	5,431,119
Error %	3%	5%	4%	10%	3%	8%

Of the 383,424 cases examined the great majority of individual errors are small, e.g. 41,872 less than 0.1 ha. The distribution of these predominance errors is shown in table 3.5 and a cumulative error plot for those predominance errors over 2.5 ha is shown in figure 3.7.

Table 3.5 Distribution of predominant land use errors

Predominance Error (ha)	Count
0	326,807
>0.1	41,872
>1	13,567
>10	1,524
>100	152
>1,000	8

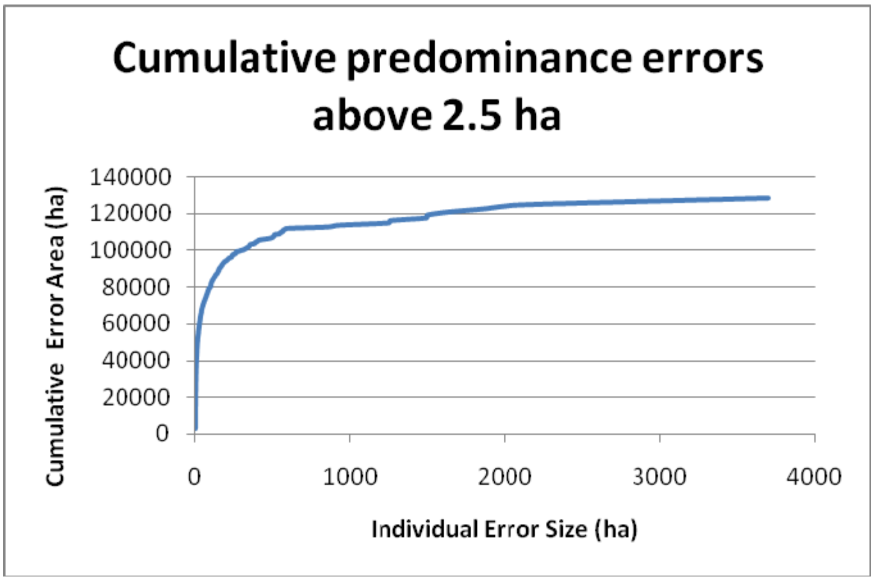

Figure 3.7 Distribution of predominance errors

It should be noted that the figures presented for predominance only show the overestimation per class, since predominance, by definition, excludes one or more other land uses. Bias in the distribution between the increases and decreases in E&I land uses can also be estimated per field and mapped as an indication of reliability of the IACS based E&I land use estimates (this was, however, beyond the resources of this scoping study).

An alternative strategy of retaining all the LU data for each field was considered. While this would avoid some of the issues associated with the use of predominant LU, it would require a field-oriented analysis of LUC using the vector mapping data. Overlaying two large and complex vector datasets to generate a LUC map cannot be accomplished in a single process (due to limitations of the GIS software). The overlay process thus has to be done on regional basis and recombined. This is a lengthy and complex process. Differences in field boundaries between years (~15% of field boundaries are altered each year) mean that a LUC change vector map is also substantially more complex than the component LU maps. Where multiple LUs are present this spatial overlay would also result in a non-spatial matrix of LUC per field that would then have to be disaggregated across the soils present per field. Determining the soils present per field would also require a vector overlay process of similar complexity to generating the LUC map. The output from a vector based LU-LUC-MU overlay would be formidably complex (the combination to two 380,000+ field boundary datasets, with an average of more than one LU per field, combined with a 20,000+ polygon soil map). Within this complex dataset there would be areas with identical combinations of LU-LUC-MU that could be aggregated together. This process of aggregation could, however, only take place within a grid defined by the 5km climate/CC grid cells since the climate of each cell is unique. This aggregation process would also be complicated by the need for a further spatial overlay process to account for LU-LUC-MU polygons that cross the climate/CC cell boundaries. Thus, while the thresholds in the predominant LU approach introduce errors, alternative approaches are computationally impractical and introduce their own uncertainties.

Classification Creep

A further issue that is worth noting is that there can be creep in the reporting of some classes. This is particularly of concern between grass over five years and rough grazing IACS classes since these are in E&I classes grassland and semi-natural respectively. The substantial conversion seen between 2000 and 2009 of predominant grassland to predominant semi-natural (361,028 ha) may reflect alteration in IACS classification preferences for those filling in the form rather than any change on the ground.

None of these caveats is, however, so serious that it invalidates the analysis undertaken, but they either suggest valuable lessons for implementations (phasing or recoding to E&I classes) or raise issues that need to be considered further (differentiating key LU classes in the IACS mapping).

3.3 Land management data

Land management data are not currently captured in the IACS database in sufficient spatial detail to be used by the models. Therefore fertiliser and manure use, for example, are not included.

3.4 Integration of spatial forestry and IACS datasets

A key challenge is the integration of spatial forestry and IACS datasets. Potential solutions to this issue have been considered.

The ICAS database and map define the area of 400,928 ha of land uses that would fall under the E&I forestry classification in 2009. This is a substantial increase in coverage over 2000 perhaps reflecting that Scottish Forestry Grant Scheme payments began to be administered through IACS. See table 3.6 for a breakdown of areas in 2009

Table 3.6 IACS codes included in E&I Forestry Class

IACS Class[13]	2000 Count of Occurrences	2000 Area (ha) from predominant LU mapping[14]	2009 Count of Occurrences	2009 Area (ha) from predominant LU mapping[14]
ALMONDS	N/A	N/A	N/A	N/A
HAZELNUTS	N/A	N/A	N/A	N/A
NON-FOOD SETASIDE - FOREST TREES SHORT CYCLE	N/A	N/A	N/A	N/A
NON-FOOD SETASIDE - TREES SHRUBS AND BUSHES	N/A	N/A	N/A	N/A
NORMAL SETASIDE - 5 YEAR UNDER FWS	N/A	N/A	N/A	N/A
NORMAL SETASIDE - 5 YEAR UNDER WGS	N/A	N/A	N/A	N/A
NORMAL SETASIDE - WILD BIRD COVER	N/A	N/A	N/A	N/A
NURSERY - ORNAMENTAL TREES	N/A	N/A	15	109
OPEN WOODLAND(GRAZED)	2,902	11,444	3,268	16,922
PISTACHIOS	N/A	N/A	N/A	N/A
SHORT ROTATION COPPICE	N/A	N/A	11	44
SHORT ROTATION COPPICE ENERGY	N/A	N/A	81	571
STRUCTURAL SETASIDE - EX 5 YEAR STILL IN FWS	N/A	N/A	N/A	N/A
STRUCTURAL SETASIDE - WGS, FWPS OR SFGS	N/A	N/A	N/A	N/A
TREES SHRUBS & BUSHES	N/A	N/A	2,681	9,221
WALNUTS	N/A	N/A	N/A	N/A
WOODLAND AND FORESTRY	N/A	N/A	23,276	374,060
WOODLAND/FORESTRY WITH UNIQUE FIELD IDENTIFIER	N/A	N/A	N/A	N/A
	2,902	11,444	29,332	400,928

From the Economic report on Scottish Agriculture 2009 the area of woodland within agricultural areas for Scotland is 317,341 ha so the IACS woodland classes are perhaps including some areas of woodland beyond the areas defined by the JAC as agricultural. The woodland areas recorded in the National Inventory of Woodland and Trees in 2001 was 1,281,471 ha so it is clear that woodland is substantially under-represented in the IACS dataset.

A definitive source of forestry data is being developed through the Forestry Commission - the National Forest Inventory (NFI)[15]. This comprises a woodland map due for publication in spring 2011 and a 5

[13] Each IACS category which has ever appeared (2000-2009) was included in the E&I classification. As a result some of these categories (e.g. set-aside) do not appear in either year.
[14] Some categories do appear, but only ever as a minor portion of a mixed land use field (e.g. the nut categories), and thus never appear as predominant land uses.

yearly rolling field survey programme of 15,000 1 ha squares (3,000 pa). The map is derived from 1:10,000 aerial photography[16] with interim annual updates from FC estate[17], forestry grants and remote sensing[18] (satellite) sources. Triangulation of data sources with an element of ground truthing as being practised through the NFI is central to mapping land use change. This approach will become even more robust as historical time series are established.

Integration of the NFI with IACS mapping would greatly improve the E&I land use mapping but still with a decadal separation for complete coverage.

A complementary source of regularly updated forestry data could be Ordnance Survey (OS) MasterMap which has complete coverage and differentiates ~60 categories in which forestry appears. The MasterMap update schedule for forestry is, however, uncertain and dependant on the OS programme of rural updates. For forestry these updates are again based on aerial photography and would have a return period of about five years. The MasterMap product supplied is date stamped but special arrangements would likely be needed to maintain an archive of yearly snapshots rather than only the most recent data.

3.5 *Summary - analysis of data included in IACS forms*

Data coverage

IACS coverage is extensive (and near comprehensive for agricultural areas). It has continued to grow with a wider range of land based businesses now making claims via SRDP. It would likely have near complete coverage if an area-based payments scheme for Pillar I payments of CAP were introduced (in whatever form). The most significant limitation is in terms of forestry cover which is seriously under represented (<30% of Scotland's woodland is mapped in IACS). The integration of IACS with NFI should be a priority.

Data updates

IACS is the only spatial LU dataset updated on an annual basis.

Data Accessibility

Protocols for access to IACS data for research use via RPID have been established and have worked well.

Data quality

There are limitations of the IACS dataset but these have been identified (see below) and where possible mitigation strategies implemented to minimise their impact. Where there are remaining limitations, approaches to quantifying their effect have been tested or proposed (particularly with regard to bias between E&I classes).

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[15] The National Forest Inventory is the successor to the National Inventory of Woods and Trees (NIWT). Outputs from NIWT were published in 2001 but the base photography that they were derived from dates back to 1987-9 in Scotland.

[16] FC currently uses Ordnance Survey aerial photography, generally 1-5 years old. For Scotland the new NFI map is predominantly based on 2004-09 aerial photography.

[17] FC maintains a 'live' inventory ('Forester GIS') of the National Forest Estate i.e. updated for in year felling and restocking from operational data.

[18] It is straightforward to update woodland area for felling from low resolution satellite imagery once a definitive 'woodland mask' is set. The NFI map establishes this mask and can use currently available 2007 satellite data for felling updates. 2009 satellite data (via GMES) is likely to be available in summer 2011. Conversely it is impossible to update woodland area for new planting or regeneration from aerial photography or satellites because these are not 'visible' from the sky until several years post establishment (actual time depends on species, density, competing vegetation, image type etc).

1) Cross checking claim and map polygon data for consistency is needed. It can also be valuable to cross check rented-in and rented-out areas both for area and for land use.
2) Classification reliability and creep. From 2009 there is a commitment to the collection of the land use classes required by the JAC and these are more than sufficiently specific for the current requirements of the ECOSSE and CEH GHG Inventory. There is, however, the need for care in interpreting annual change in land use. In some cases near the boundaries of classes (particularly between grassland and semi-natural) classification may change in response to other drivers such as SFP cross compliance criteria.
3) Extrapolation from claims to fields occurs in 6% of mapped area. This represents a significant source of uncertainty for LU and LUC. It is recommended that all LU should be reported so that claim and mapped areas match.

Use of predominant land use for each field

This makes generating the unique combinations computationally feasible and introduces acceptably small errors (2% of area). These errors have known distributions, both in terms of land use and spatially so the reliability of the input datasets can be mapped. The errors could also be modelled through ECOSSE and CEH GHG Inventory to determine the uncertainty introduced by the predominance estimates. Ideally E&I land uses should not be included in the same mapped polygons.

Compatibility with ECOSSE and CEH GHG Inventory

IACS can provide the land use information required and in a format that is compatible with the modelling without extensive pre-processing. The approach to the land use data results in a datasets that, while large, is computationally feasible. Since each unique combination of LU, LUC, soil, climate and previous LU change can be processed independently, the IACS based dataset is particularly amenable to the use of multiple-processors, task framing and/or parallel computing approaches to speed up the analysis.

IACS data is available and suitable to use for inventory purposes, and at a much finer spatial and temporal resolution compared to than the Countryside Survey data previously used. Using IACS data in place of Countryside Survey data as activity (area) increases the spatial resolution of simulations from a 20km to a 100m grid, an increase in spatial resolution by a factor of 40,000. In addition, the annual update of IACS data has the potential to increase the temporal resolution from decadal to annual, an increase in temporal resolution by a factor of 10.

4. Modelling methodology required to use IACS data in ECOSSE and CEH GHG Inventory

Phase 2 focuses on the modelling methodology required to use the IACS data in the CEH GHG Inventory and ECOSSE. Routines to pre-process the data or revised input/output routines have been developed for both models and the mapping of the LU categories used in IACS onto the LU types used in the models has been completed. The models have been rerun using the new IACS derived database, so addressing the objective to compare and contrast the results with the current inventory, highlighting the strengths and weaknesses of both approaches. Estimates of changes in soil C content obtained from the CEH GHG Inventory and ECOSSE with and without IACS data are compared. The ability of the systems to make use of this more detailed data and the availability of other data, especially soils data has been assessed. The comparisons included in this report are summarised in table 4.1.

Table 4.1 Summary of comparisons included in this report (simulation 1 compared to simulation 2)

	Simulations 1			Simulations 2		
Report Section	Land use data	Scale & Period	Emission model	Land use data	Scale & Period	Emission model
4.1	LULUCF	Scotland (2000-2009)	Single Exponential/CFlow	IACS (2000-2009)	100m (2000-2009)	Single Exponential/CFlow
4.2	CS	20km (1950-2009)	ECOSSE	CS (1950-1999) IACS (2000-2009)	100m (2000-2009)	ECOSSE
4.2	CS	20km (2000-2009)	ECOSSE	IACS (2000-2009)	100m (2000-2009)	ECOSSE
4.3	IACS (2000-2009)	Scotland (2000-2009)	Single Exponential/CFlow	IACS (2000-2009)	100m (2000-2009)	ECOSSE

Note: LULUCF is Countryside Survey data with additional information on afforestation and deforestation from the Forestry Commission; CS = Countryside Survey data at 20km grid resolution ; Single Exponential / CFlow is the current CEH methodology used in the UK GHG Inventory.

4.1 Calculation of soil carbon stock changes by the UK CEH GHG Inventory method

4.1.1 IACS area and soil series data

As explained in more detail in Section 3, overlaying of IACS maps with Soil Series maps produced areas of unique combinations of IACS class change between 2000 and 2009 and soil map units. Each of these combinations was assigned a Unique ID (UID). The CEH methods for calculating soil C stock change do not use climate and so, in contrast to the UID areas for the ECOSSE model which required some 90,000 UIDs (termed WITH-CLIM UIDs), only 6711 were required for the CEH GHG Inventory approach (termed NO-CLIM UIDs). For each of the UIDs, a list of Soil Series was provided via the soil map unit. The IACS codes had been combined into Forest, Semi-natural, managed Grassland and Cropping groups plus groups for Other, Unclassified and “Not in IACS” areas.

CEH holds a database of soil C data which provides C density under Forest, Semi-natural, Pasture (managed Grassland) and Arable (Cropping) land use for depths to 1m for each Soil Series (Bradley et al 2005). These values are averages from many locations across the country and are therefore taken to be the value of density that will be reached when land use is stable. Using these data the soil carbon stock in the area of each NO-CLIM UID was calculated for 2000 and 2009.

4.1.2 Application of UK CEH GHG Inventory methods to IACS data

The CEH GHG Inventory uses two different models in calculating change in soil C stock change. For afforestation of any land the CFlow model is used.

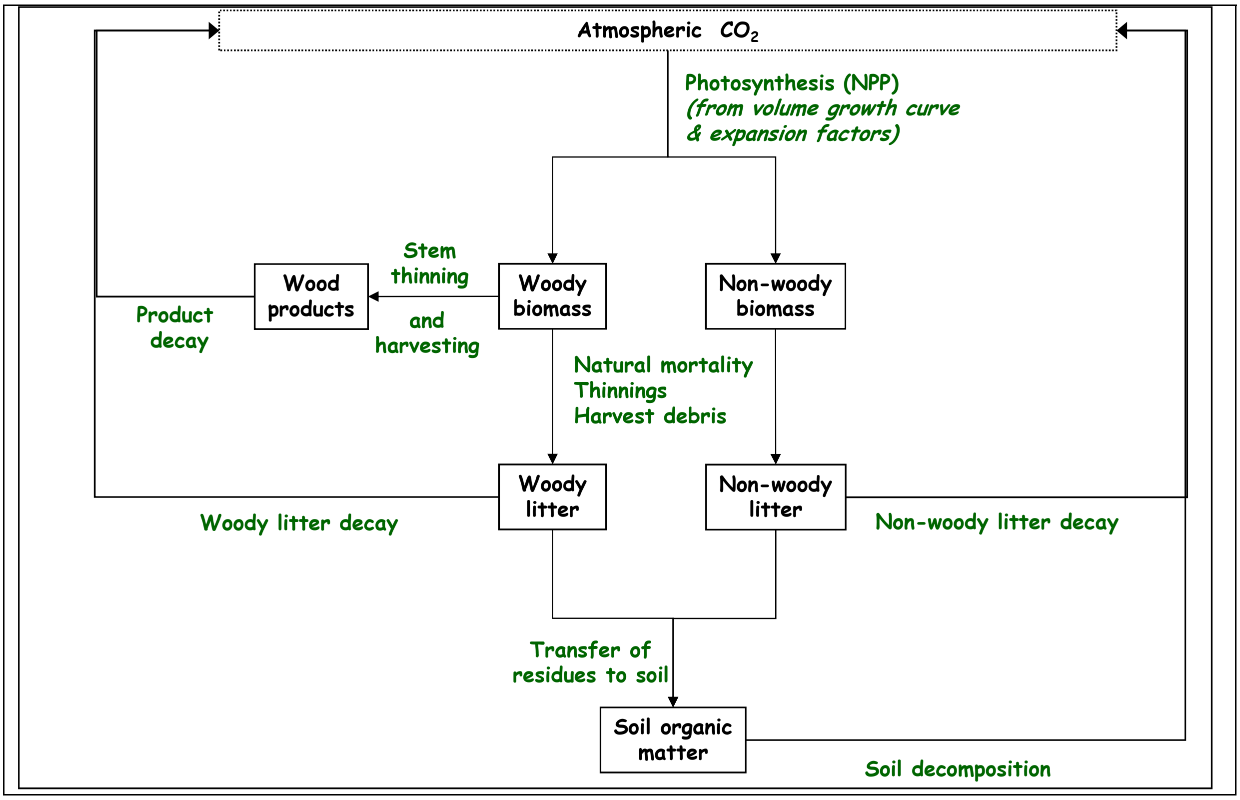


Figure 4.1 Flows of carbon in CFlow model of forest growth

The CFlow model also estimates forest biomass C change (figure 4.1) but such data are not discussed here. For all other land use change a single exponential model is used to describe soil C density change from that for the initial land use to that for the final land use.

$$F_t = Af_t = Ak(C_f - C_o)e^{-kt}$$

where F_t is annual change in carbon stock in year t, A is land area undergoing a specific transition in use, C_0 is carbon density of initial land use, C_f is carbon density after change to new land use and k is time constant of change.

Different rates of change are assumed for a) land use transitions that involve a change to more intense management (commonly but not exclusively resulting in a loss of soil carbon) and b) land use transitions that involve a change to less intense management (commonly but not exclusively resulting in a gain of soil carbon). For the CEH GHG Inventory, uncertainty in these rates is taken into account by assuming that for 99% change in C density a loss in Scotland will take between 50 and 150 years and a gain in soil C will take between 300 and 750 years. The latter time is long to allow for the slow build-up of C in the typically organic rich soils of Scotland. In the CEH GHG Inventory a Monte Carlo method is used where calculations are rerun many times with different random selections of rate from these ranges to account for any non-linearity in the models and to provide uncertainty estimates of calculated C stock changes. Here, for simplicity, the median rates for 99% loss of 100 years and 99% “gain” of 525 years are used.

Each NO-CLIM UID has an area, but for those that include land use change the pattern of change over the period 2000 to 2009 is not known. It was therefore assumed that all of the change occurred in 2005. This is the assumption used in the ECOSSE model implementation but alternatively it could have been assumed that the area change between 2000 and 2009 occurred equally through the period. In the CEH GHG Inventory, afforestation data is available annually but other land use change is derived from the intermittent sampling of the Countryside Survey, which is then assumed to occur uniformly between the sampling dates. To minimise the effect of this mid-point change assumption results are presented for soil C change from 2010 onwards. Previous tests have shown that there are very small differences in results after the end of the period of observed land use change based on the mid-point change and the uniform spread but obviously for years within the change period there will be major differences.

To use the area and soil C density data for each NO-CLIM UID with land use change, 3 patterns of soil C density were estimated based on the assumption of change occurring in 2005. The CFlow model provided the change in soil C after afforestation. It was assumed that the tree planting was mixed 36% broadleaf and 64% conifer, based on Forestry Commission statistics for the period. Initial losses of soil C due to site establishment were also taken into account. The model provided soil C change per unit area per year and values were calculated for each year from 2010 to 2050 (figure 4.2). The sawtooth pattern is due to inputs of C to the soil due to the management practice of thinning out the forest at regular intervals to allow the remaining trees to grow more quickly. The NO-CLIM data provides the area for each UID where afforestation occurred.

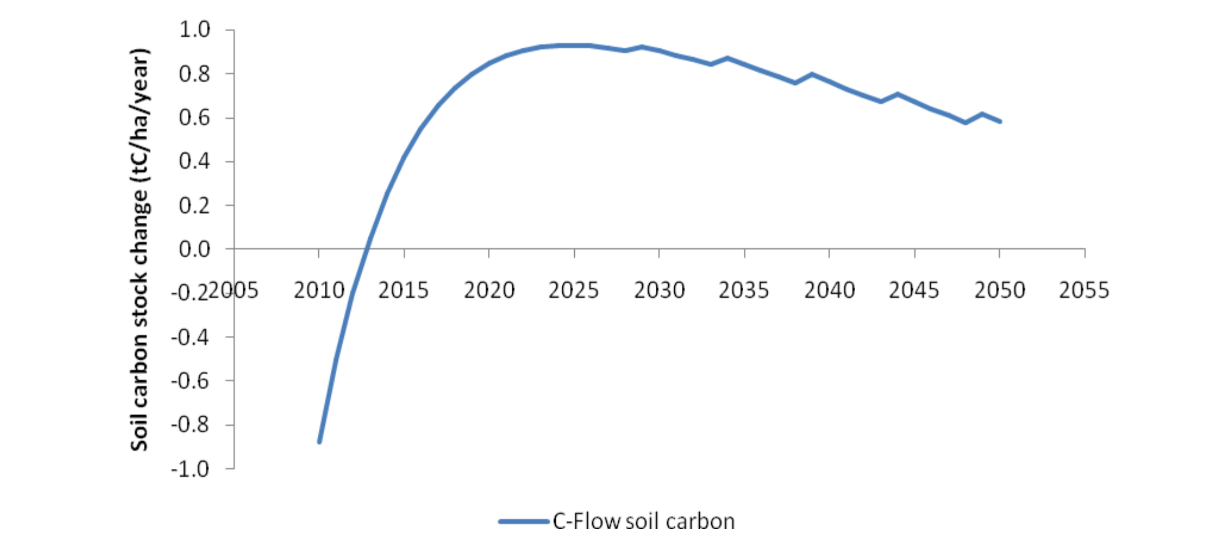


Figure 4.2 Pattern of annual soil carbon stock change produced by CFlow model. Unit area of afforestation (36% broadleaf and 46% conifer) was assumed to be planted in 2005.

For other land use change the exponential model provided the proportion of the overall soil C change occurring in each year from 2010 to 2050 (figure 4.3). The NO-CLIM data provided an area and soil C density change between “stable” values (hence soil C stock change between “stable” values) for each UID where non-afforestation land use change occurred. The soil C stock change is negative for losses and positive for gains.

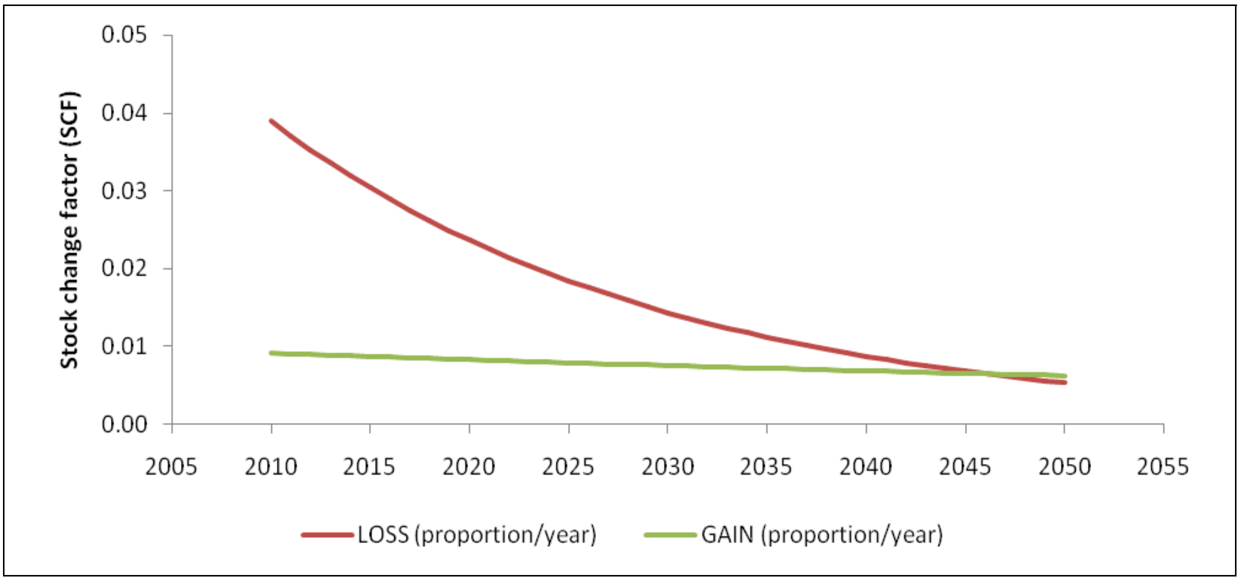


Figure 4.3 Pattern of change of annual soil carbon stock losses or gains. Stock change (tC/ha/year) = SCF*(difference in "stable" soil carbon density between final and initial land use)

4.1.3 Land use groups

The IACS data was grouped into Forestry, Semi-natural, managed Grassland and Cropping. In the CEH GHG Inventory Semi-natural and managed Grassland are not distinguished and additionally there is a Settlement (developed land) group, giving the 5 land groups, Forest Land, (IPCC)Grassland, Cropland, Settlements and Other . In order to allow comparison of C stock change results, the CEH GHG Inventory land types are initially used here by combining model results from UID area where the IACS Semi-natural and managed Grassland types occurred. The models were run by grouping the UIDs into the LULUCF GHG land groups, calculating the areas and soil density stock change for the changes from initial to final group and then applying the time pattern of stock change for each of these.

4.1.4 CEH GHG Inventory data for comparison

The Land Use Land Use Change and Forestry (LULUCF) Sector of CEH GHG Inventory for Scotland includes many more activities than are possible to include from the IACS data. The LULUCF CEH GHG Inventory includes biomass C stock changes, especially conifer and broadleaf forests, emissions due to e.g. biomass burning and application of lime in farming. The biomass and soil C stock changes are calculated for years from 1990 to the present, and projected into the future, due to land use change from 1950 onwards and afforestation from 1920 onwards. However the focus here is on soil C stock changes, estimated from the IACS data. It must be recognised that these data are for the period 2000-2009 only, do not include all Scottish land and there is no information on the tree species that were planted. It was decided therefore to extract from the CEH GHG Inventory system soil C stock from 2010 to 2050 change due to the afforestation (FC data) and other LUC (Countryside Survey) only for the period 2000-2009. This approach was taken for two reasons: a) substituting the IACS data into the GHG system could have been carried out but it would have been much more difficult to determine the source of any differences to the standard LULUCF CEH GHG Inventory due to the many other recent and historical activities included therein and b) time constraints within the present project.

4.1.5 Areas, soil carbon densities and soil carbon stock changes from IACS data

The data from the NO-CLIM UIDs were grouped into a land use change matrix using the LULUCF CEH GHG Inventory land types. This matrix is shown in table 4.2. It can be seen that the IACS data has some significant omissions. Some 42% of Scotland is not included and, as noted above, there are no Settlement data. There is also a not inconsiderable amount of "Other" and "Unclassified" land where soil C changes could not be taken into account. The areas in the diagonal of the matrix are those where land use has not occurred between 2000 and 2009.

Table 4.2. Land use change matrix (ha) based on IACS data for 2000 and 2009 in Scotland using CEH GHG Inventory land groups. Land transitions where soil carbon stock changes have been estimated are highlighted

Land use in 2000 / **Land use in 2009**	**Forest Land**	**IPCC Grassland**	**Cropland**	**Settlements**	**Other**	**Unclass-ified**	**Not in IACS**	**Area 2009**
Forest Land	7,750	47,020	5,317	0	17,007	0	0	77,094
IPCC Grassland	2,095	3,276,386	122,735	0	40,297	0	0	3,441,513
Cropland	241	84,299	891,594	0	15,265	0	0	991,399
Settlements	0	0	0	0	0	0	0	0
Other	110	2,008	1,478	0	3,737	0	0	7,333
Unclassified	0	293	162	0	57	0	0	512
Not in IACS	0	0	0	0	0	0	3,324,670	3,324,670
Area 2000	10,196	3,410,006	1,021,286	0	76,363	0	3,324,670	7,842,521

The Scottish average soil C stock change from stable value in initial land use (LU) group to that in final land group for different land transitions estimated from the IACS/Soil Series/ Soil database information is shown in table 4.3.

Table 4.3 Average change in soil carbon density (tC/ha) across Scotland between each different land use (LU) estimated from IACS areas combined with soil association maps and soil series characteristics from the Bradley et al (2005) soil carbon database. CFlow model is used for soil carbon stock changes for all afforestation.

Initial / **Final**	**Forest Land**	**IPCC Grassland**	**Cropland**	**Settlements**
Forest Land		*CFlow*	*CFlow*	
IPCC Grassland	-24.8	0	32.7	
Cropland	-107.7	-34.7	0	
Settlements				

4.1.6 Soil carbon stock change by CEH method driven by IACS LUC

For each of the 6 transitions available from the IACS data, either the CFlow or single exponential time model of soil C stock change was applied as appropriate. Figure 4.4 shows the resulting gains and losses of soil carbon from 2010 to 2050 due to the IACS LUC between 2000 and 2009 in Scotland. The CEH GHG Inventory land types are used for reference. The largest stock change can be seen to be that due to losses as land is converted from Grassland to Cropland. These losses reduce quickly due to the assumed rate of change (99% of change takes 100 years). Afforestation of Grassland contributes the largest gains in soil C after the initial losses (due to forest establishment practices). Cropland to Grassland conversion also contributes a large gain in soil carbon stock which reduces only slowly due to the assumption of 99% change taking 525 years. Other transitions contribute smaller changes. Note that the relative size of the contributions is a combination of the area changing and the soil carbon density in those areas. An alternative view on these results using the matrix format is provided in tables 4.4, 4.5 and 4,6 for 2010, 2020 and 2050 respectively.

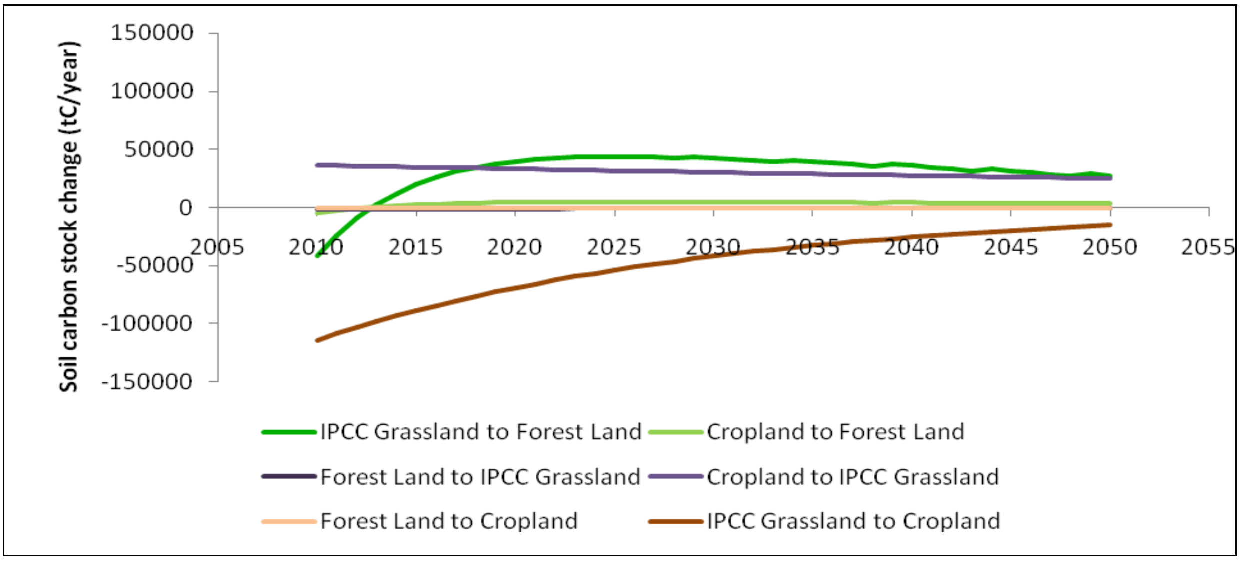


Figure 4.4 Annual stock change of soil carbon (tC) in IACS data for period 2000 to 2009 in Scotland

Table 4.4 Annual soil carbon stock change (tC) in 2010 due to land use change between 2000 and 2009 from Scottish IACS data. No data for Settlements in IACS. Right hand column shows net stock change for all conversion to each land use

Initial / **Final**	**Forest Land**	**IPCC Grassland**	**Cropland**	**Settlements**		**Net stock change**
Forest Land	0	-41,252	-4,665		***To Forest Land***	*-45,916*
IPCC Grassland	-2,022	0	36,467		***To IPCC Grassland***	*34,445*
Cropland	-1,010	-114,026	0		***To Cropland***	*-115,037*
Settlements					***To Settlements***	*0*
					Total	*-126,508*

Table 4.5 Annual soil carbon stock change (tC) in 2020 due to land use change between 2000 and 2009 from Scottish IACS data. No data for Settlements in IACS. Right hand column shows net stock change for all conversion to each land use.

Initial / **Final**	**Forest Land**	**IPCC Grassland**	**Cropland**	**Settlements**		**Net stock change**
Forest Land	0	39,767	4,497	0	***To Forest Land***	44,264
IPCC Grassland	-1,227	0	33,154	0	***To IPCC Grassland***	31,928
Cropland	-613	-69,160	0	0	***To Cropland***	-69,773
Settlements	0	0	0	0	***To Settlements***	0
					Total	6,418

Table 4.6 Annual soil carbon stock change (tC) in 2050 due to land use change between 2000 and 2009 from Scottish IACS data. No data for Settlements in IACS. Right hand column shows net stock change for all conversion to each land use.

Initial / Final	Forest Land	IPCC Grassland	Cropland	Settlements		Net stock change
Forest Land	0	27,354	3,093	0	***To Forest Land***	30,447
IPCC Grassland	-274	0	24,915	0	***To IPCC Grassland***	24,641
Cropland	-137	-15,432	0	0	***To Cropland***	-15,569
Settlements	0	0	0	0	***To Settlements***	0
					Total	39,520

These tables show that the net annual change in soil C changes from a loss of 126,508 tC in 2010 to a gain of 39,520 tC in 2050. Stock change due to all transitions to Forest Land, Grassland and Cropland are listed. This type of grouping is used in reporting of LULUCF CEH GHG Inventory data to the UNFCCC and will be used for comparison of these results, based on IACS data, with the results included in the CEH GHG Inventory for the same period of LUC. It can be seen that for conversions to Forest Land the two constituent transitions follow the same pattern of loss then gain. The constituents of stock change for conversions to Cropland are always losses. However the two constituents of conversions to Grassland have the opposite sign: Forest Land to Grass land stock changes are losses but Cropland to Grassland changes are gains. Figure 4.5 shows the time pattern of the grouped transitions. The overall pattern is therefore of initially large annual losses of soil C but after about 10 years the net annual soil C stock change becomes positive, with a slow decline over subsequent decades.

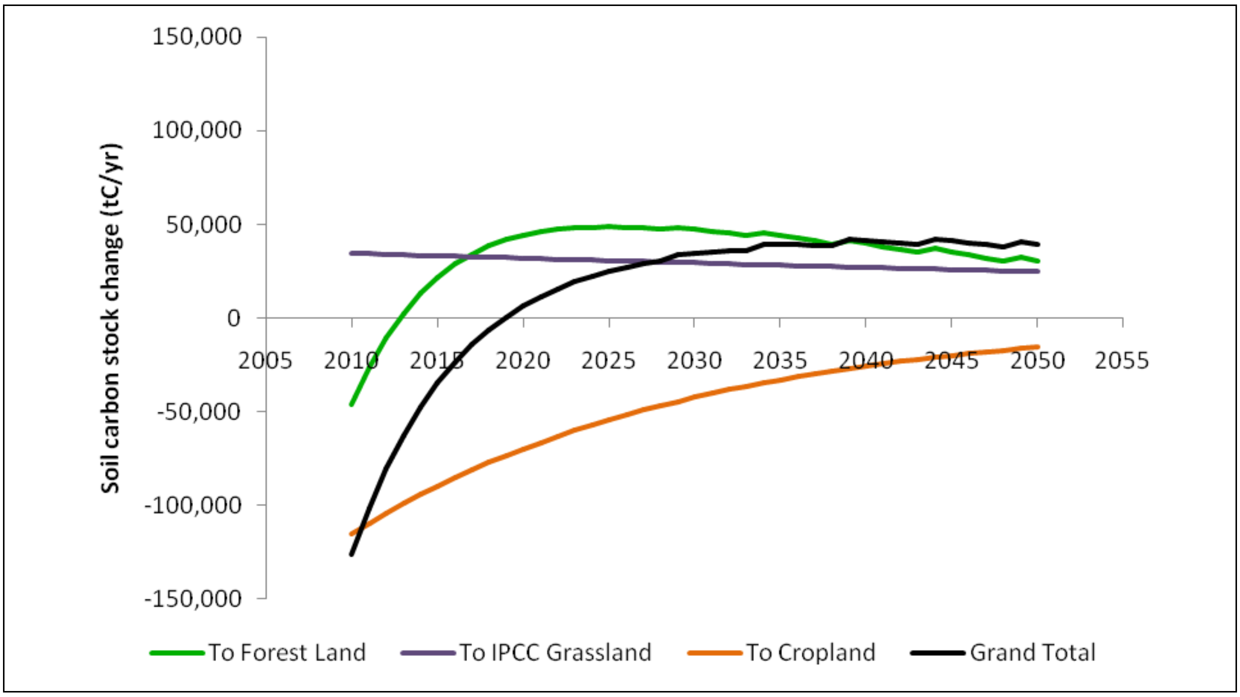


Figure 4.5 Annual soil carbon stock change (tC) due to IACS LUC between 2000 and 2009. Data are grouped to show values for sum of transitions to each land use type and for all transitions

4.1.7 Comparison of changes in soil C calculated by the CEH GHG Inventory using IACS data with that calculated using Forestry Commission statistics and Countryside Survey data

Using IACS data with Semi-natural and Grassland classes combined into one class

The LULUCF CEH GHG Inventory uses data from annual Forestry Commission statistics for afforestation and from the Countryside Survey (CS) for other land use change. The last available land use change matrices from the CS cover the period 1990 to 1998. Analysis of the CS 2007 data is underway but until that is completed data from the earlier period is being used for subsequent years i.e. the results described here are for land use change between 1990 and 1998 applied to the period of 2000 to 2009. The resulting land use change matrix, obtained by combining the Forestry Commission (2000-2009) and CS data and as used in the CEH GHG Inventory is shown in table 4.7. In addition to the Forest, Grass and Crop areas data, is also shown for Settlements i.e. developed land. Only those areas where land use change was recorded are shown, but with additional data, on other land where use did not change, the matrix underlying the LULUCF CEH GHG Inventory includes all areas of Scotland.

Table 4.7 Matrix of areas (ha) of land use change in Scotland from 2000 to 2009 from Countryside Survey and Forestry Commission statistics as used in LULUCF CEH GHG Inventory.

Initial LU Final LU	Forest Land	IPCC Grassland	Cropland	Settlements
Forest Land		63,286	3,292	880
IPCC Grassland	3,015		168,388	6,759
Cropland	58	214,038		2,706
Settlements	176	22,210	1,228	

As described in Sections 2.2 and 2.5 the calculations in the LULUCF CEH GHG Inventory are made for the whole of Scotland and therefore it was necessary to estimate a weighted average of soil C density change between different land uses that took into account the fact that land use change does not occur uniformly across all soil series. The underlying soil C densities were from the Bradley et al (2005) database as used in the IACS based calculations above, but the method of estimating density changes between land uses at the Scotland scale was significantly different. The weighted soil C density changes between the various non-forest land uses in their stable state from the LULUCF CEH GHG Inventory are shown in table 4.8. The CFlow model is used separately to estimate soil C stock change for afforestation.

Table 4.8 Average change in soil carbon density (tC/ha) across Scotland between different land use (LU) estimated from Countryside Survey areas combined with soil series characteristics from the Bradley et al (2005) soil carbon database as used in LULUCF CEH GHG Inventory. CFlow model is used for soil carbon stock changes for all afforestation.

Initial LU Final LU	Forest Land	IPCC Grassland	Cropland	Settlements
Forest Land		*CFlow*	*CFlow*	*CFlow*
IPCC Grassland	-51.8		88.5	189.4
Cropland	-165.4	-89.7		96.2
Settlements	-253.3	-187.5	-66.7	

The annual stock changes of soil C in Scotland due to LUC over the period from 2000 to 2009 that are included in the LULUCF CEH GHG Inventory were extracted and are shown in figure 4.6. The data for conversions To Settlements are excluded to allow more direct comparison with the results based on the IACS data. The contribution of the To Settlements changes that are in the CEH GHG Inventory, but not available from IACS data, are in illustrated in figure 4.7. Note also that although the Grand Total of GHG C stock changes shown here agrees with that in Inventory reports the distribution of the values across the To IPCC Grassland and To Cropland groups will differ from those in the reports due to additional weighting to reflect deforestation data from Forestry Commission and other sources.

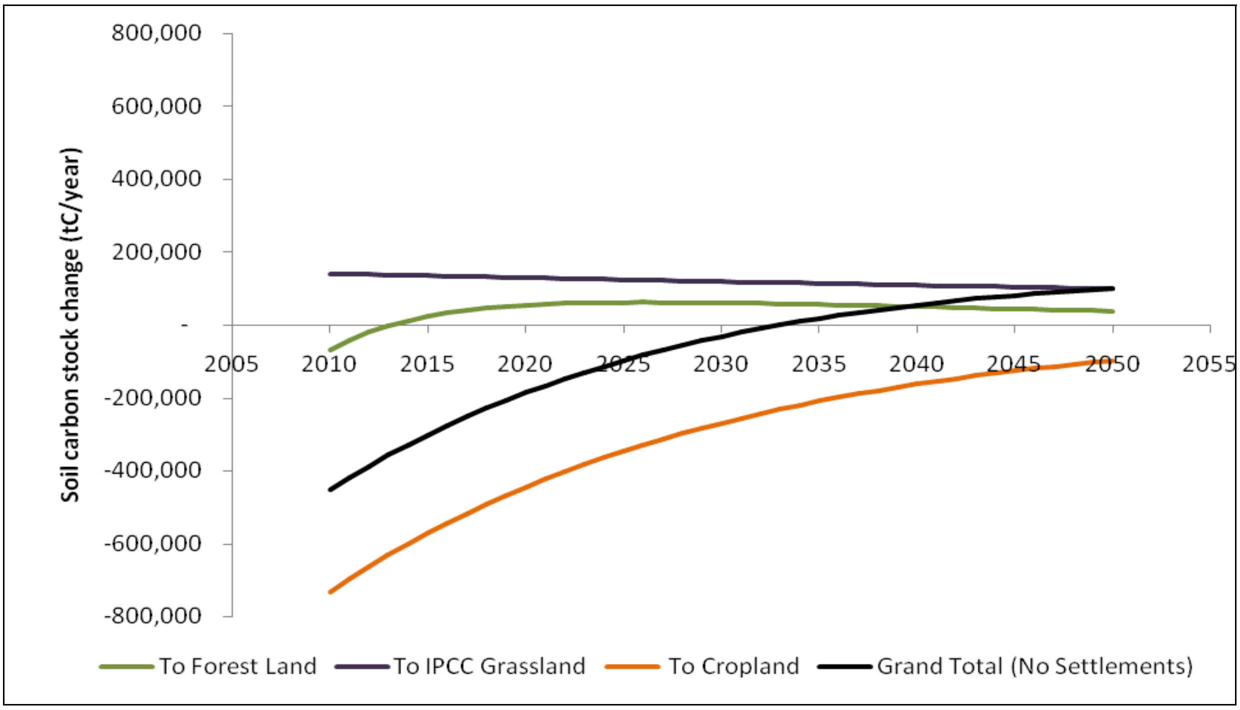


Figure 4.6 Annual soil carbon stock change (tC) due to CS/FC data between 2000 and 2009 as included in LULUCF CEH GHG Inventory. Data are grouped to show values for sum of transitions to each land use type and for all transitions but *excluding* stock changes due to LU transitions to Settlements

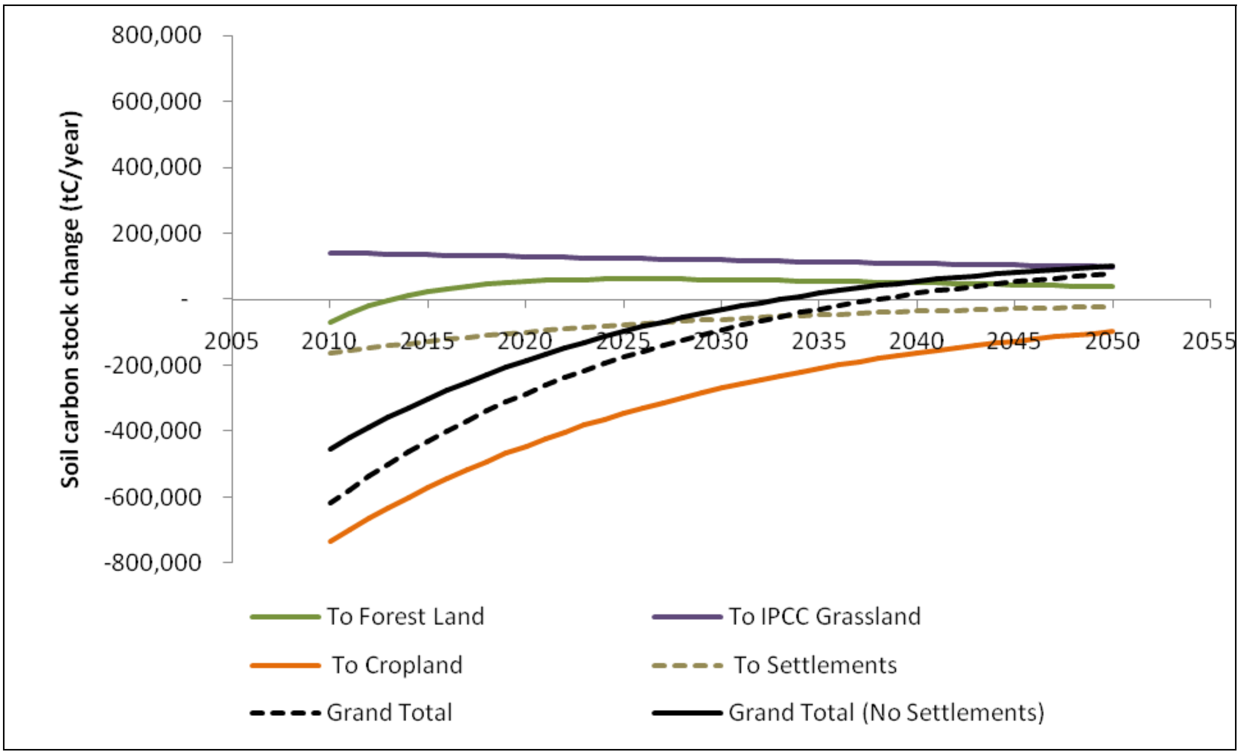


Figure 4.7. Annual soil carbon stock change (tC) due to CS/FC data between 2000 and 2009 as included in LULUCF CEH GHG Inventory. Data are grouped to show values for sum of transitions to each land use type and for all transitions *including* stock changes due to LU transitions to Settlements

Comparing figures 4.6 and 4.5 shows the same patterns of change for IACS and LULUCF CEH GHG Inventory based data. However there are some large differences in the values. The soil C stock changes for conversion To Cropland and To Grassland are estimated to be numerically much larger by the LULUCF CEH GHG Inventory data. Afforestation soil C stock changes are similar from the two approaches.

These differences are readily explainable when the LUC area data of table 4.2 (IACS) and table 4.7 (LULUCF CEH GHG Inventory) are compared. The afforestation data is similar from the two sources and as the CFlow model is used in both cases the similarity of the estimated soil C stock changes is unsurprising.

For the To Cropland group the main contributor to the stock changes is the conversion from Grassland to Cropland and the area for this is about 3 times greater in the LULUCF CEH GHG Inventory (CS 1990-1998) data than in the IACS data. Comparing the "stable to stable" soil C density changes in table 4.3 (IACS) and table 4.8 (LULUCF CEH GHG Inventory), it can be seen that the value for the Grassland to Cropland transition is also greater in the LULUCF CEH GHG Inventory data than in the IACS approach. These differences between the two approaches for both area of land converted and changes in soil carbon density are the main contributors to the overall stock changes. Differences in carbon stock change between the two approaches also vary with time because the single exponential model with fast turnover for C losses emphasises C stock losses in the early years after a land use change.

Using IACS data with separate Semi-natural and managed Grassland classes

The IACS data has two different grassland classes – Semi-natural and managed Grassland. For comparison with the CEH GHG Inventory approach these were combined but of course any land use change between these classes may also cause changes in soil carbon stock. The analyses based on the IACS data were therefore re-run with these two grassland classes treated separately.

The soil C density differences between the various classes are shown in table 4.9. The IACS land use change data with the two grassland classes is shown in table 4.10. The patterns of changes in annual soil carbon stock change are shown in figure 4.8.

Table 4.9 Average change in soil carbon density (tC/ha) across Scotland between different land use (LU) estimated from IACS areas combined with the soil map and component Soil Series characteristics from the Bradley et al (2005) soil carbon database. Grassland is treated as two separate classes of Semi-natural and managed Grassland. CFlow model is used for soil carbon stock changes for all afforestation.

Initial LU / **Final LU**	**Forestry**	**Semi-Natural**	**Grassland**	**Cropping**	**Settlements**
Forestry	0.0	*CFlow*	*CFlow*	*CFlow*	
Semi-Natural	-12.0	0.0	2.3	57.6	
Grassland	-64.6	-13.9	0.0	31.2	
Cropping	-107.7	-69.7	-32.2	0.0	
Settlements					

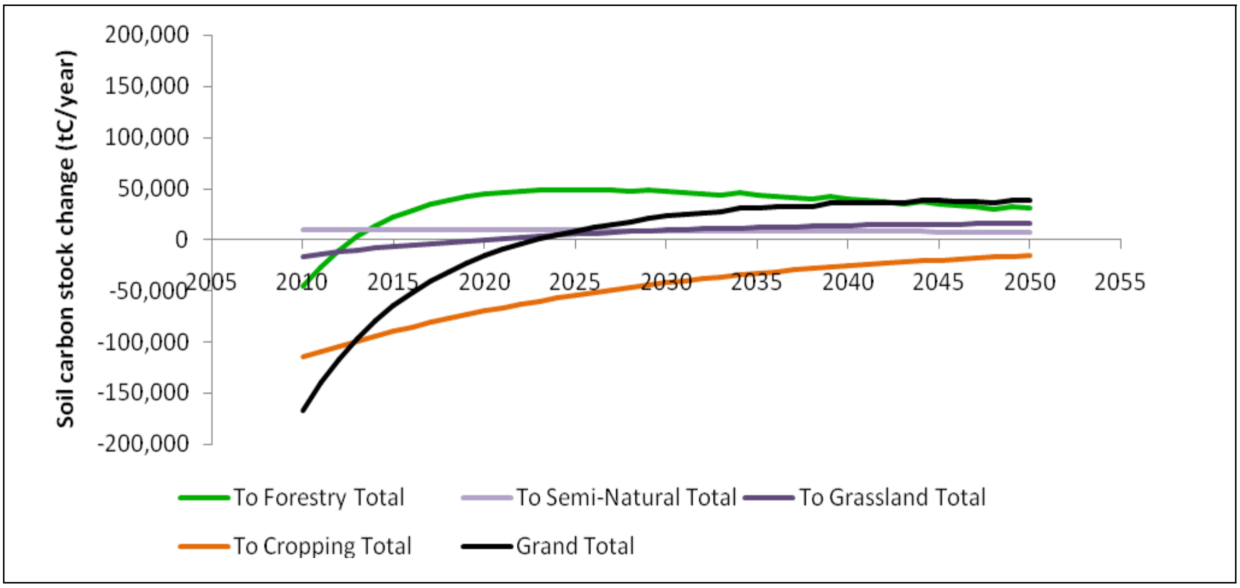


Figure 4.8. Annual soil carbon stock change (tC) due to IACS LUC between 2000 and 2009. Data are grouped to show values for sum of transitions to each land use type and for all transitions. Grassland is treated as two separate classes of Semi-natural and managed Grassland

Comparing figure 4.8 with figure 4.5 and the information in tables 4.11, 4.12 and 4.13 shows that having two grass classes introduces more net stock change. In 2010 using two grass classes the net grand total of soil C stock change is – 167,028 tC/year (a loss) for two grassland classes compared to -126,508 tC/year with one grassland class as used in the LULUCF CEH GHG Inventory. So using two grassland classes introduced an extra net loss of soil C of ~40,000 tC/year in 2010 due to net transfers between Semi-natural and managed Grass classes. This difference decreases with time so that by 2050 the net grand total of soil C stock change was 39,520 tC/year (a gain) using one grassland class and was 37,996 tC/year using two grassland classes.

Table 4.10. Land use change matrix (ha) based on IACS data for 2000 and 2009 in Scotland using groupings of IACS land types, including two grassland groups of Semi-natural and managed Grassland. Land transitions where soil carbon stock changes have been estimated are highlighted.

Initial **Final**	**Forestry**	**Semi-natural**	**Grassland**	**Cropland**	**Settlements**	**Other**	**Unclassified**	**Not in IACS**	**Area 2009**
Forestry	7,750	33,586	13,434	5,317	-	17,007	-		77,094
Semi-natural	1,587	2,181,460	352,235	6,914	-	36,049	-		2,578,245
Grassland	508	88,193	654,498	115,821	-	4,248	-		863,268
Cropland	241	5,732	78,567	891,594	-	15,265	-		991,399
Settlements	-	-	-	-	-	-	-		-
Other	110	677	1,331	1,478	-	3,737	-		7,333
Unclassified	-	87	206	162	-	57	-		512
Not in IACS								3,324,670	3,324,670
Area 2000	10,196	2,309,735	1,100,271	1,021,286	-	76,363	-	3,324,670	7,842,521

Table 4.11 Annual soil carbon stock change (tC) in 2010 due to land use change between 2000 and 2009 from Scottish IACS data. No data for Settlements in IACS. Net stock change for all conversion to each land use is compared for approach with one and two classes of Grassland.

Initial LU **Final LU**	**Forestry**	**Semi-Natural**	**Grassland**	**Cropping**	**Settlements**	**Two Grass classes**		***One Grass class***	
Forestry	0	-29,466	-11,786	-4,665	0	**To Forestry**	-45,916	*-45,916*	***To Forest Land***
Semi-Natural	-745	0	7,229	3,618	0	**To Semi-natural**	10,103		
Grassland	-1,278	-47,749	0	32,849	0	**To Grassland**	-16,178		
						To IPCC Grassland	*-6,075*	*34,445*	***To IPCC Grassland***
Cropping	-1,010	-15,551	-98,475	0	0	**To Cropping**	-115,037	*-115,037*	***To Cropland***
Settlements	0	0	0	0	0	**To Settlements**	0		
						Total	-	-	

							167,028	*126,508*	

Table 4.12 Annual soil carbon stock change (tC) in 2020 due to land use change between 2000 and 2009 from Scottish IACS data. No data for Settlements in IACS. Net stock change for all conversion to each land use is compared for approach with one and two classes of Grassland

<u>Initial LU</u> **<u>Final LU</u>**	**Forestry**	**Semi-Natural**	**Grassland**	**Cropping**	**Settlements**	**Two Grass classes**		***One Grass class***	
Forestry	0	28,405	11,362	4,497	0	**To Forestry**	44,264	*44,264*	***To Forest Land***
Semi-Natural	-452	0	6,572	3,290	0	**To Semi-natural**	9,410		
	-775	-28,961	0	29,865	0	**To Grassland**	128		
Grassland						***To IPCC***	*9,539*	*31,928*	***To IPCC***
Cropping	-613	-9,432	-59,728	0					
						Total	-15,971	*6,418*	

Table 4.13 Annual soil carbon stock change (tC) in 2050 due to land use change between 2000 and 2009 from Scottish IACS data. No data for Settlements in IACS. Net stock change for all conversion to each land use is compared for approach with one and two classes of Grassland.

<u>Initial LU</u> **<u>Final LU</u>**	**Forestry**	**Semi-Natural**	**Grassland**	**Cropping**	**Settlements**	**Two Grass classes**		***One Grass class***	
Forestry	0	19,539	7,815	3,093	0	**To Forestry**	30,447	*30,447*	***To Forest Land***
Semi-Natural	-101	0	4,939	2,472	0	**To Semi-natural**	7,310		
	-173	-6,462	0	22,443	0	**To Grassland**	15,808		
Grassland						***To IPCC Grassland***	*23,118*	*24,641*	***To IPCC Grassland***
Cropping	-137	-2,105	-13,327	0	0	**To Cropping**	-15,569	*-15,569*	***To Cropland***
Settlements	0	0	0	0		**To Settlements**	0		
						Total	37,996	*39,520*	

4.1.8 Conclusions from CEH GHG Inventory calculations

The IACS data for 2000 and 2009 have been shown to be a useful source of land use change information for Scotland. The format of information combining land use and soil information at a fine scale can be used to generate land use change matrices for Scotland and hence estimate soil carbon stock changes. The basic soil carbon density change models of the LULUCF CEH GHG Inventory were used with the IACS data and the resulting soil carbon stock changes were compared from those included in the LULUCF CEH GHG Inventory databases. For afforestation the two approaches produced similar results primarily because the total afforestation recorded in the IACS data for 2000 to 2009 was similar to that from the Forestry Commission statistics used in the CEH GHG Inventory. There were significant differences between soil carbon stock changes for non-afforestation land use change as estimated by the two approaches. These were due to differences in the areas recorded by IACS and Countryside Surveys for each class of land use change and differences in Scotland-wide averages of soil carbon density in different land uses within the two approaches.

This pilot study therefore suggests the following advantages and disadvantages of using IACS data in the LULUCF CEH GHG Inventory

Advantages

1. IACS data likely to be more representative of farm industry land use than Countryside Survey
2. The IACS land use data in combination with fine scale soil series data is likely to provide improved soil carbon density estimates
3. Potential to be available annually
4. Collection of data is an official Scottish Government administration task
5. Trusted by SG departments

Disadvantages

1. Does not cover all Scotland with 42% of land missing– e.g. no developed land data, some forestry missing, grassland not in a farming business excluded
2. Recording quality improving but remains variable
3. Not available for all years – 2000 to 2009 was chosen as period with best coverage.
4. Future changes in farm support mechanisms may make IACS data unnecessary and therefore recording will cease.

4.2 ECOSSE simulations

The calculations of changes in soil C completed in previous work funded by the Scottish Government (Smith et al., 2009) used land use change data provided by CEH, based on annual Forestry Commission statistics for afforestation and Countryside Survey data for other land uses. To maintain backward compatibility with this work, reformatting of data was done in a pre-processor stage before running the model.

4.2.1 Translation of IACS unique combinations into ECOSSE input data

Land use change data – 2000-2009

As explained in more detail in Section 3, overlaying of IACS maps with soil series and climate maps produced unique combinations of climate, soil and land use in 2000 and 2009. The fraction of land use change used in the ECOSSE inputs was derived from the change in land use between 2000 and 2009. Data were entered in the same format as used in previous work, but the meaning of data items was modified, allowing the results to be linked directly back to the unique combinations and so readily mapped. This small change in formatting was used to avoid the need for the spatially explicit IACS data to be passed to the University of Aberdeen or to CEH, as this was held under licence by

Macaulay. The revised format is shown in table 4.14. Note, *Miscanthus* and short rotation coppice land use categories were unused in these simulations. The area of land occupied by this unique combination was entered as 1,000,000m^2 (i.e. the full "1km^2" cell). This was necessary to avoid confusion in the scaling of results output for the unique combinations. Scaling for the actual area of the unique combination cell was then done within a spreadsheet at post-processor stage to allow the total change in soil C across Scotland to be calculated.

Table 4.14 Revision of land use and land use change data input to ECOSSE – Changes to previous format are highlighted in bold

Line	Data items used for simulations using IACS data
1 2 to end	Title ObjectID (Unique combination) (previous format = Grid ID (20km)) Grid ID (1km) Eastings coordinate (m) Northings (m) Area occupied by this unique combination used in scaling result (m^2) (in previous format = Area of 1km grid occupied by land (m^2)) – here entered as 1000000 and scaling done in postprocessor stage Fraction of cell under arable at start Fraction of cell under gardens at start (not used) Fraction of cell under semi-natural/natural at start Fraction of cell under other at start (not used) Fraction of cell under grassland at start Fraction of cell under sea at start (not used) Fraction of cell under forestry at start Fraction of cell under urban at start Fraction of cell under water at start Fraction of cell under land with non-CORINE def. at start Fraction of cell under *Miscanthus* at start Fraction of cell under short rotation coppice at start LU1 changed to LU2 in decade 1 (ha decade^{-1} (20km)$^{-2}$) LU1=Forestry; LU2=Forestry; LU1=Natural/Semi-natural; LU2=Forestry; LU1=Grassland; LU2=Forestry; LU1=Arable; LU2=Forestry; LU1=Miscanthus; LU2=Forestry; LU1=SRC; LU2=Forestry; LU1=Forestry; LU2= Natural/Semi-natural; LU1=Natural/Semi-natural; LU2= Natural/Semi-natural; LU1=Grassland; LU2= Natural/Semi-natural; LU1=Arable; LU2= Natural/Semi-natural; LU1=Miscanthus; LU2= Natural/Semi-natural; LU1=SRC; LU2= Natural/Semi-natural; LU1=Forestry; LU2=Grassland; LU1=Natural/Semi-natural; LU2=Grassland; LU1=Grassland; LU2=Grassland; LU1=Arable; LU2=Grassland; LU1=Miscanthus; LU2=Grassland; LU1=SRC; LU2=Grassland; LU1=Forestry; LU2=Arable; LU1=Natural/Semi-natural; LU2=Arable; LU1=Grassland; LU2=Arable; LU1=Arable; LU2=Arable; LU1=Miscanthus; LU2=Arable; LU1=SRC; LU2=Arable; LU1=Forestry; LU2= Miscanthus; LU1=Natural/Semi-natural; LU2= Miscanthus; LU1=Grassland; LU2= Miscanthus; LU1=Arable; LU2= Miscanthus; LU1=Miscanthus; LU2= Miscanthus; LU1=SRC; LU2= Miscanthus; LU1=Forestry; LU2=SRC; LU1=Natural/Semi-natural; LU2=SRC; LU1=Grassland; LU2=SRC; LU1=Arable; LU2=SRC; LU1=Miscanthus; LU2=SRC; LU1=SRC; LU2=SRC. Fraction of LU1 changed to LU2 in decade 2 (ha decade^{-1} (20km)$^{-2}$) LU1=Forestry; LU2=Forestry… …LU1=Other; LU2=Other. Fraction of LU1 changed to LU2 in decade 3 (ha decade^{-1} (20km)$^{-2}$) LU1=Forestry; LU2=Forestry…

	…LU1=Other; LU2=Other. Fraction of LU1 changed to LU2 in decade 4 (kha yr^{-1} (20km)$^{-2}$) LU1=Forestry; LU2=Forestry… …LU1=Other; LU2=Other. Fraction of LU1 changed to LU2 in decade 5 (kha yr^{-1} (20km)$^{-2}$) LU1=Forestry; LU2=Forestry… …LU1=Other; LU2=Other. Fraction of LU1 changed to LU2 in decade 5 (kha yr^{-1} (20km)$^{-2}$) LU1=Forestry; LU2=Forestry… …LU1=Other; LU2=Other.

Historical land use and land use change data

In the simulations that used historical land use change data, the historical data were matched with the IACS data through the grid reference provided for the climate data. Because the climate data were provided on a 5km grid, whereas historical land use change data were provided on a 20km grid, this allowed correct positioning of the land use changes. This approach was taken to circumvent problems with the University of Aberdeen obtaining a licence for the full IACS dataset. In future work, it is recommended that IACS data should be passed together with cell coordinates to reduce the work required to assign historical land use and land use change data.

Soils and long term average weather data

Soils data were used in the same format as in previous simulations. The soils data was provided for each unique combination cell and were again entered into the model using only small changes in formatting as shown in table 4.15. Long term average weather data, available on a 5km grid, were matched to the unique combination cell through the climate identification number provided with the unique combination cell.

Table 4.15 Revision of soil, and long term average weather data input to ECOSSE – Changes to previous format are highlighted in bold

Line	Data items used for simulations using IACS data
1	Title
2 to end	ObjectID (Unique combination) (previous format = Grid ID (20km)^2)) Grid ID (1km^2) Eastings coordinate (m) Northings (m) Area occupied by this unique combination used in scaling result (m^2) (in previous format = Area of 1km^2 grid occupied by land (m^2)) – here entered as 1000000 and scaling done in postprocessor stage Dominant soil series 1 Percentage of cell under dominant soil series 1 (here entered as 100% as unique combinations were specified for one soil type at a time) Soil wetness class series 1 Dominant soil series 2 Percentage of cell under dominant soil series 2 (here entered as 0% as unique combinations were specified for one soil type at a time) Soil wetness class series 2 Dominant soil series 3 Percentage of cell under dominant soil series 3 (here entered as 0% as unique combinations were specified for one soil type at a time) Soil wetness class series 3 Dominant soil series 4 Percentage of cell under dominant soil series 4 (here entered as 0% as unique combinations were specified for one soil type at a time) Soil wetness class series 4 Dominant soil series 5 Percentage of cell under dominant soil series 5 (here entered as 0% as unique combinations were specified for one soil type at a time) Soil wetness class series 5 Remaining percentage of cell under other soil series (here entered as 0% as unique combinations were specified for one soil type at a time) Net primary production kgC m^{-2} x 1000 for this cell Long Term Average Rainfall (mm month-1) Jan to Dec Long Term Average Air Temperature (°C month-1) Jan to Dec

	Longitude Latitude

The soil characteristics were entered through an additional file that used the same format as used in the calculations based on SSKIB data undertaken in the ECOSSE 2 project (Smith et al., 2009). One file is provided for each land use class (table 4.16). Note *Miscanthus* and short rotation coppice land use classes are not used in these simulations.

Table 4.16 Input of soil characteristics to ECOSSE

Line	Data items used for simulations using IACS data
1 2 to end	Title Series code number (match numbers used in NPP and soil information file) Flag for impermeable layer (0 = no impermeable/rock layer; 1 = impermeable / rock layer) Depth of impermeable layer (if present) (cm) Layer 1 Top depth (cm) Bottom depth (cm) Thickness (cm) pH measured in water Percent C C (kg ha^{-1}) Percent clay Percent silt Percent sand Bulk density (g cm^{-3}) Percent stones Layer 2 Top depth (cm)… …Percent stones Layer 3 Top depth (cm)… …Percent stones Layer 4 Top depth (cm)… …Percent stones Layer 5 Top depth (cm)… …Percent stones Layer 6 Top depth (cm)… …Percent stones Layer 7 Top depth (cm)… …Percent stones Layer 8 Top depth (cm)… …Percent stones Layer 9 Top depth (cm)… …Percent stones

4.2.2 Changes in soil carbon calculated by ECOSSE using IACS data

Two simulations were completed using ECOSSE: (1) using Countryside Survey data from 1950-2009 and (2) using Countryside Survey data from 1950-1999 and IACS data from 2000-2009. This represents the best estimates of soil C changes that could be made using ECOSSE with Countryside Survey and IACS data as IACS data is unavailable before 2000. The change in soil C, averaged across Scotland is shown in figure 4.9. Across all land uses, an overall increase in the change in soil C associated with land use change is observed on moving from Countryside Survey to IACS data, suggesting a greater record of land use change through IACS than was previously assumed. Note, although there is a change of scale on moving between Countryside Survey and IACS data, because we are using values of *land use change*, rather than *land use*, this will present no artefacts due to the change of scale.

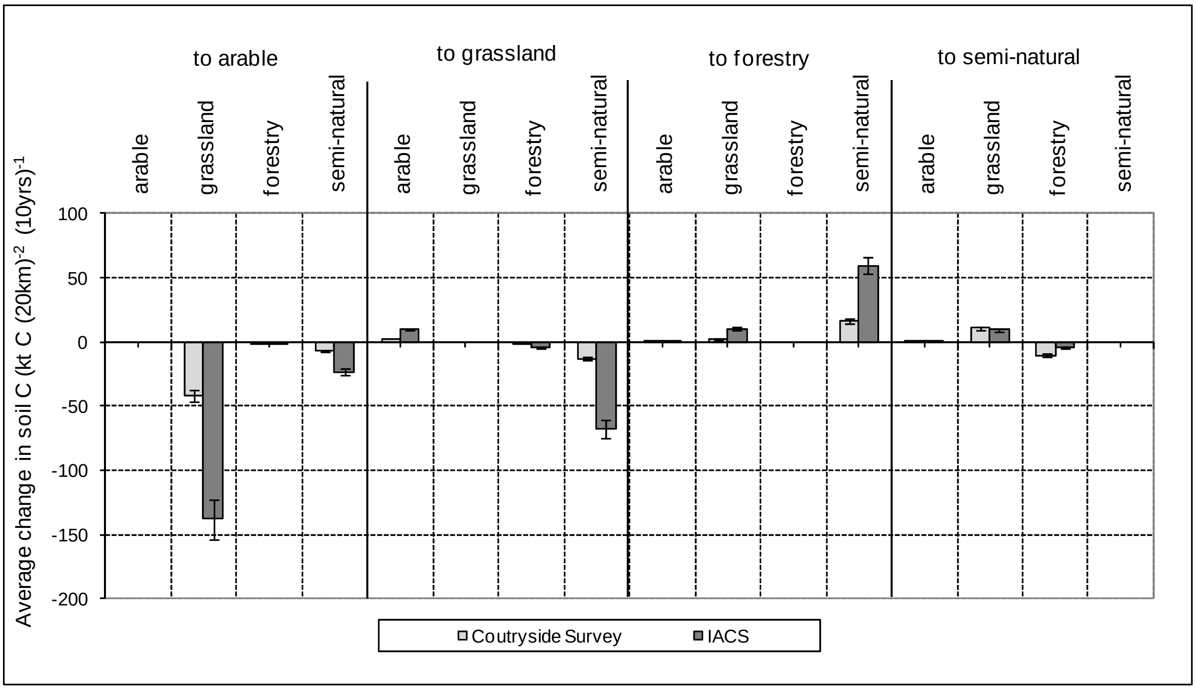


Figure 4.9 Average changes in soil carbon across Scotland between 2000 and 2009 calculated by ECOSSE using historical land use change (1950-1999) from the Countryside Survey and land use change between 2000 and 2009 from the Countryside Survey and from the IACS database as indicated in legend. Error bars represent the 11% uncertainty in national calculations estimated by Smith et al, 2009.

To more clearly distinguish the impact of using the IACS data, the simulations were rerun omitting the Countryside Survey data from 1950 to 1999. This avoids the impact of using IACS data being masked by legacy effects from land use changes in previous decades. To allow direct comparison, the simulations were also rerun using Countryside Survey data from 2000 to 2009 only. Figure 4.10 shows the comparison between the simulation using Countryside Survey data from 1950-2009 or from 2000-2009 only. Note the reduced change in soil C associated with land use grassland to arable when the data from 1950-1999 is omitted. This is due to a reduced legacy effect on soil C of the land use changes that occurred in earlier decades. A similar effect is seen for most land use changes, except for semi-natural to forestry and grassland to semi-natural, where a change in sign is observed, from an increase in soil C to a decrease. This decrease in soil C is due to the processes of cultivation which result in an initial loss of soil C, and the immaturity of the plant community resulting in decreased plant inputs in the first few years following land use change. In the simulations including land use change data from 1950-1999, the legacy effect of earlier land use change compensates for the initial decline in soil C.

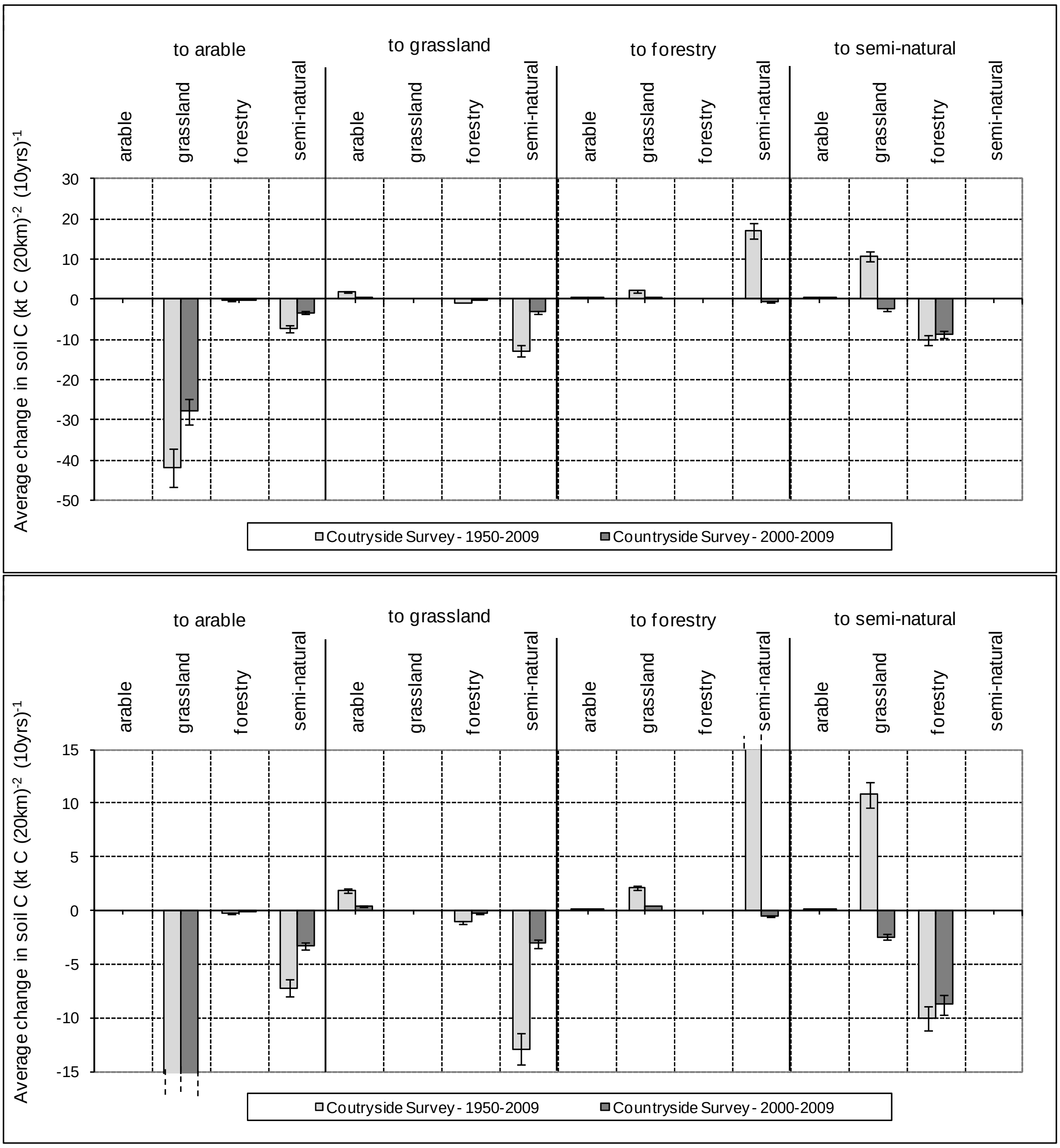


Figure 4.10 Average changes in soil carbon across Scotland between 2000 and 2009 calculated by ECOSSE with and without historical land use change (1950-1999) from the Countryside Survey and land use change between 2000 and 2009 from the Countryside Survey and from the IACS database as indicated in legend. Error bars represent the 11% uncertainty in national calculations estimated by Smith et al, 2009. Bottom plot shows the y-axis constrained to 5 to -5 kt C $(20km)^{-2}$ $(10yrs)^{-1}$, allowing smaller changes to be discerned.

Figure 4.11 shows the change in soil C averaged across Scotland for the simulations using land use change from 2000-2009 only from the Countryside Survey and IACS. A large increase in soil C losses is simulated using IACS data compared to Countryside Survey data, amounting to a 228% increase in total losses of soil C across Scotland. The greatest increases in losses are observed from land use change grassland to arable, corresponding to a 116% increase in the losses, and grassland to semi-natural, corresponding to a 3212% increase in losses. These two land use changes account for 40% and 54% of the total losses in soil C respectively.

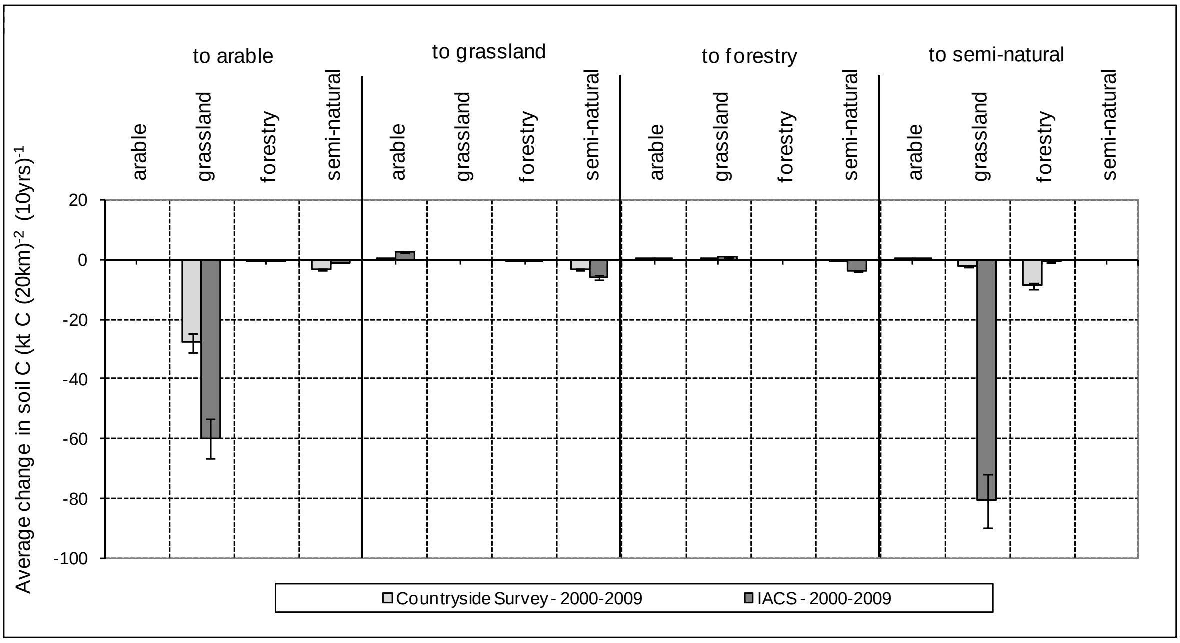


Figure 4.11 Average changes in soil carbon across Scotland between 2000 and 2009 calculated by ECOSSE using land use change data from 2000-2009 only from the Countryside Survey and from the IACS database as indicated in legend. Error bars represent the 11% uncertainty in national calculations estimated by Smith et al, 2009.

These differences in the change in soil C are in part explained by the differences in the area of land use change recorded in the two databases. The areas of land use change recorded in the Countryside Survey and in IACS assuming the definition of IACS land classes given in section 3 are shown in figure 4.12. To allow direct comparison between the Countryside Survey and IACS land use changes, these are expressed as a percentage of the total land use change recorded. This was necessary because the Countryside Survey and IACS data cover different total areas of Scotland. Figure 4.13 shows the areas of land use change actually included in the simulations. Some areas where land use changes were recorded to have occurred were not simulated, due to insufficient data being available. IACS records significantly greater land use changes than the Countryside Survey in grassland to arable and in grassland to semi-natural, explaining the increases in change in soil C discussed earlier, as well as in arable to grassland, and semi-natural to grassland, which also show an increase in the change in soil C of 518% and 95% respectively. By contrast, IACS records have significantly lower land use changes than the Countryside Survey in semi-natural to arable and forestry to semi-natural, corresponding to a decrease in the change in soil C of 59% and 92% respectively. These differences are in part due to the higher resolution of the IACS data providing improved information about land use change, but may also be due to changes in the classification of grassland and semi-natural land supplied by farmers in response to drivers such as SFP cross compliance criteria. If semi-natural and grassland areas of land use change are considered together, as shown in figure 4.14, the average difference in the areas of land use changes recorded in the Countryside Survey and in IACS is reduced from 169% to 87%. If we omit the changes in soil C due to land use change grassland to semi-natural, the increase in soil C losses simulated using IACS data compared to Countryside Survey data is reduced from 228% to 59%. If we combine grassland and semi-natural land use into one class, the increase in soil C losses simulated using IACS data compared to Countryside Survey data is 66% as shown in figure 4.15. Changes in the classification of semi-natural land and grassland, provided by farmers, is therefore an important potential source of error in the IACS data that requires further investigation.

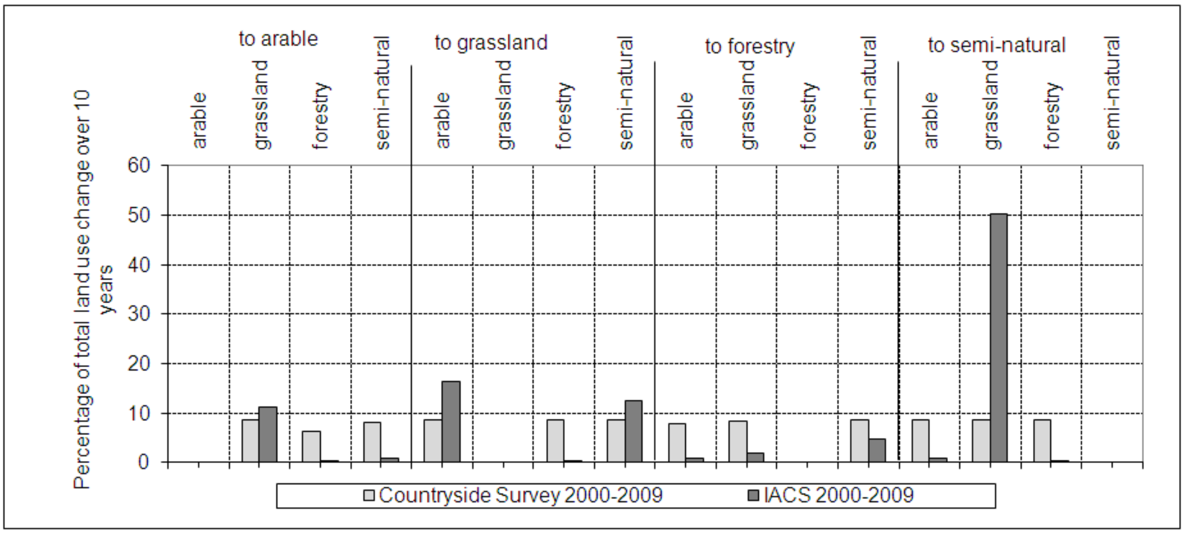


Figure 4.12 Area of land use change recorded by Countryside Survey and IACS database assuming the definition of IACS land use classes given in section 3. Because the land areas recorded by the Countryside Survey and by IACS are different, this is expressed as the percentage of the total land use change between 2000 and 2009.

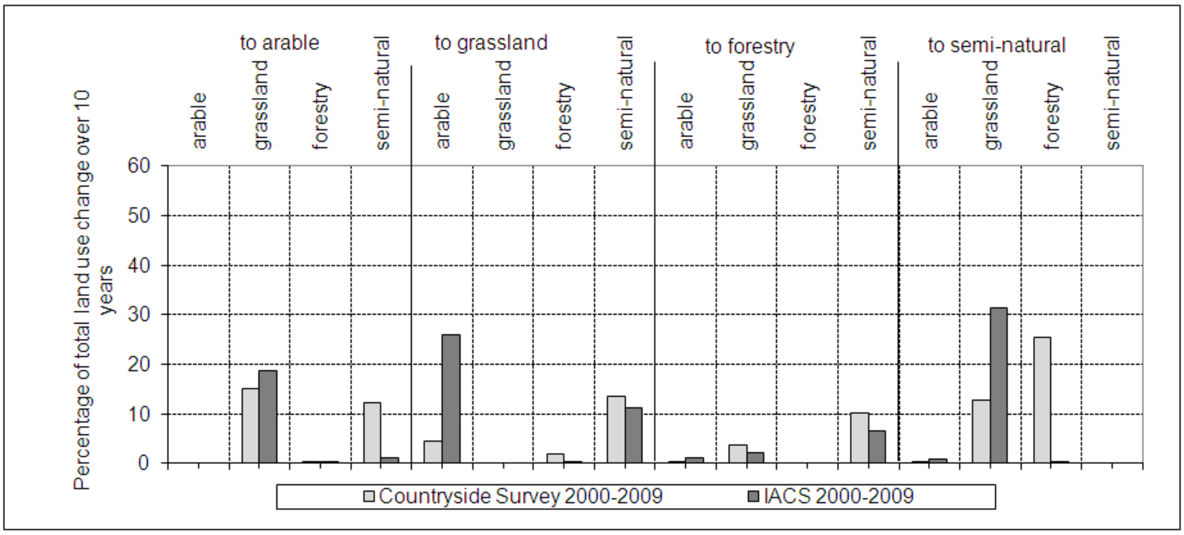


Figure 4.13 Area of land use change recorded by Countryside Survey and IACS database assuming the definition of IACS land use classes given in section 3 that includes sufficient data to be simulated. Because the land areas recorded by the Countryside Survey and by IACS are different, this is expressed as the percentage of the total land use change between 2000 and 2009.

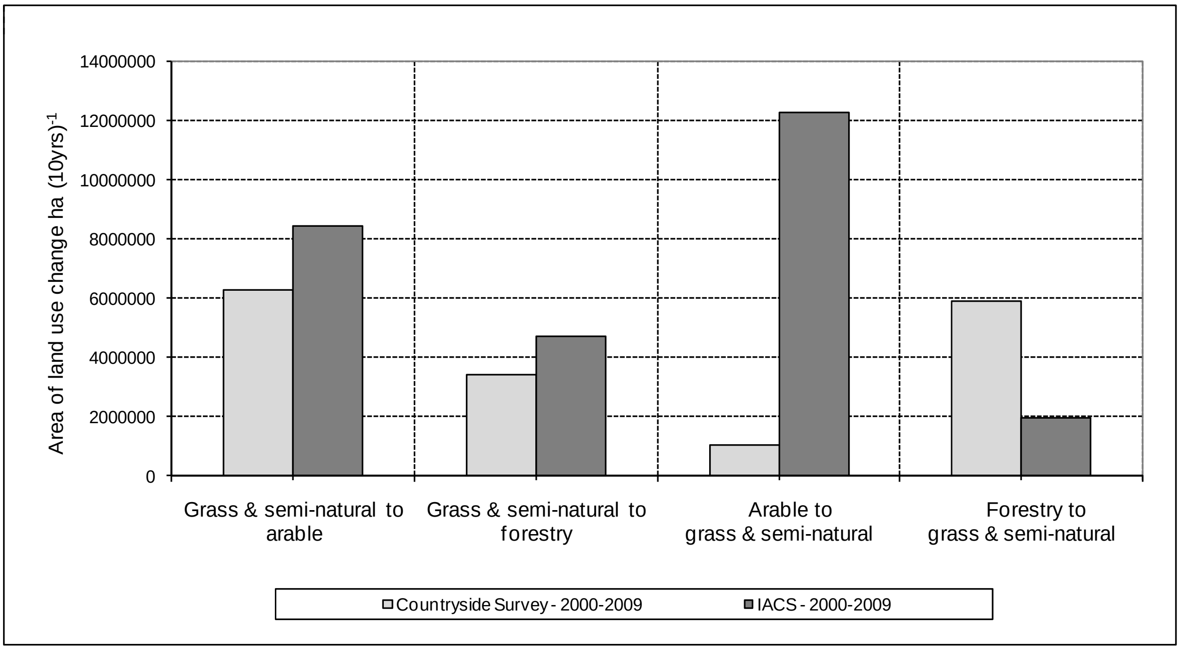


Figure 4.14 Area of land use change recorded by Countryside Survey and IACS database assuming the definition of IACS land use classes given in section 3, with grassland and semi-natural land use categories combined.

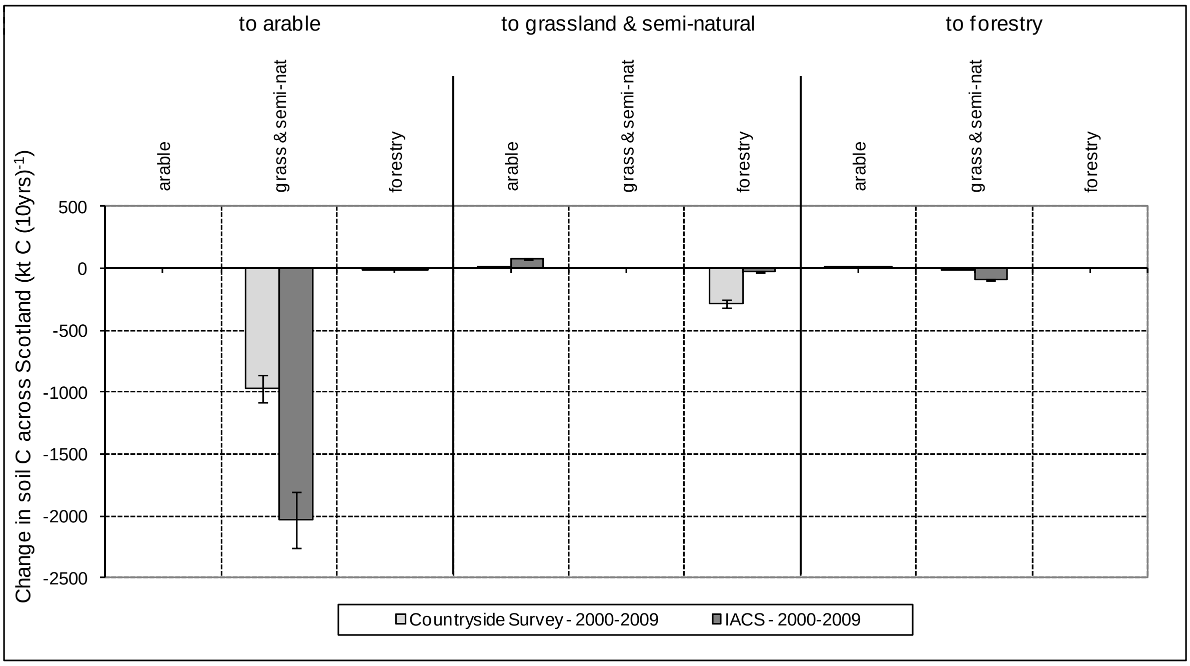


Figure 4.15 Total changes in soil carbon across Scotland between 2000 and 2009 calculated by ECOSSE using land use change data from 2000-2009 only from the Countryside Survey and from the IACS database as indicated in legend. Error bars represent the 11% uncertainty in national calculations estimated by Smith et al, 2009. Total losses of soil C calculated using IACS data is 66% greater than the losses calculated using Countryside Survey data.

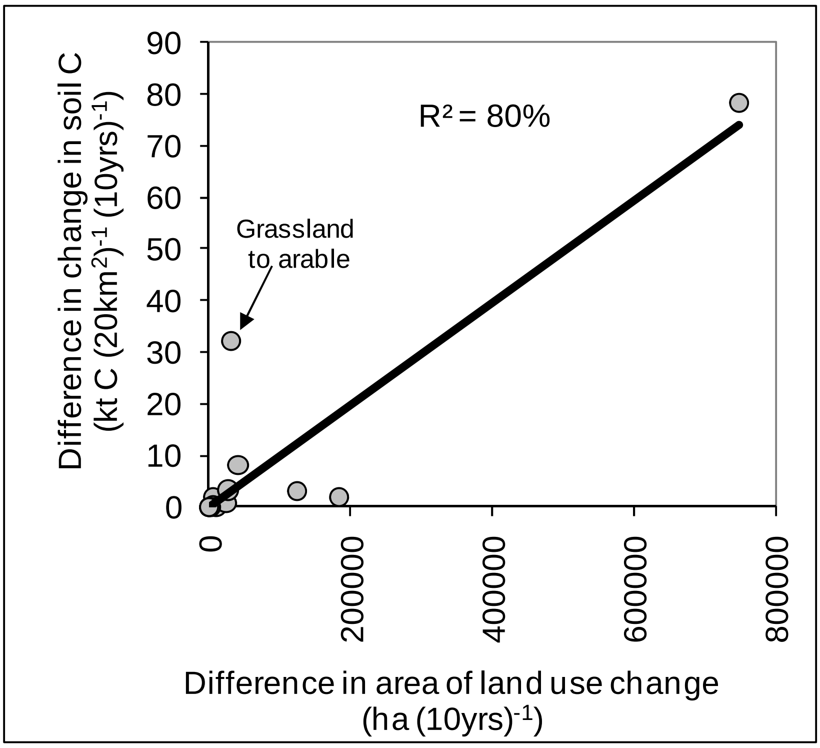


Figure 4.16 Absolute difference in change in soil C simulated using Countryside Survey or IACS land use change data from 2000-2009, plotted against absolute difference in area of land use change recorded in the two databases. The difference in land area explains 80% of the variation in the difference in change in soil C.

As shown in figure 4.16, the differences in the land use change data explain 80% of the differences in the change in soil C simulated. The land use change from grassland to arable shows a significant deviation from the linear regression between the difference in land use change recorded and the difference in soil C change simulated, suggesting that for this land use change, additional factors are contributing to the differences observed. These factors could include differences in the characteristics of the soils and climates of the areas on which the land use change is recorded due to the more detailed information being available from IACS. This is reflected in the area weighted difference in the C content of soils under the areas of arable and grassland simulated using the IACS and Countryside Survey data of land use change; for IACS data, this is -3315110

Figure 4.17 shows the area weighted average across Scotland of the difference between the steady state soil C contents of the top layer of soil under land use 2 and land use 1 for the soils recorded as having land use change from land use 1 to 2 and sufficient valid data to allow the land use change to be simulated in ECOSSE. A negative value means that the land use change would result in an overall decrease in soil C, whereas a positive value suggests an overall increase in soil C once the soil has reached steady state. This provides an indication of the impact of the soil type on the simulated change in soil C. As can be seen by comparison to figure 4.11, the difference in the steady state soil C between the two land uses in IACS data compared to the Countryside Survey data explains most of the observed difference in change in soil C in the first 10 years after land use change for the land use change grassland to arable; the ratio of results from IACS and Countryside Survey being 2.2 for both. Figure 4.18 shows the ratio of the change in soil C in the first decade after land obtained using IACS and Countryside Survey data plotted against the ratio of steady state soil C obtained from the two data sources. All land uses lie close to the 1:1 line, indicating that differences in the steady state soil C accounts for a large proportion of the differences in change in soil C simulated. Land use changes grassland to semi-natural and arable to semi-natural do not follow the 1:1 line. This is because, for these land use changes, the immaturity of the plant species is having a large impact on the change in soil C in the first decade following land use change.

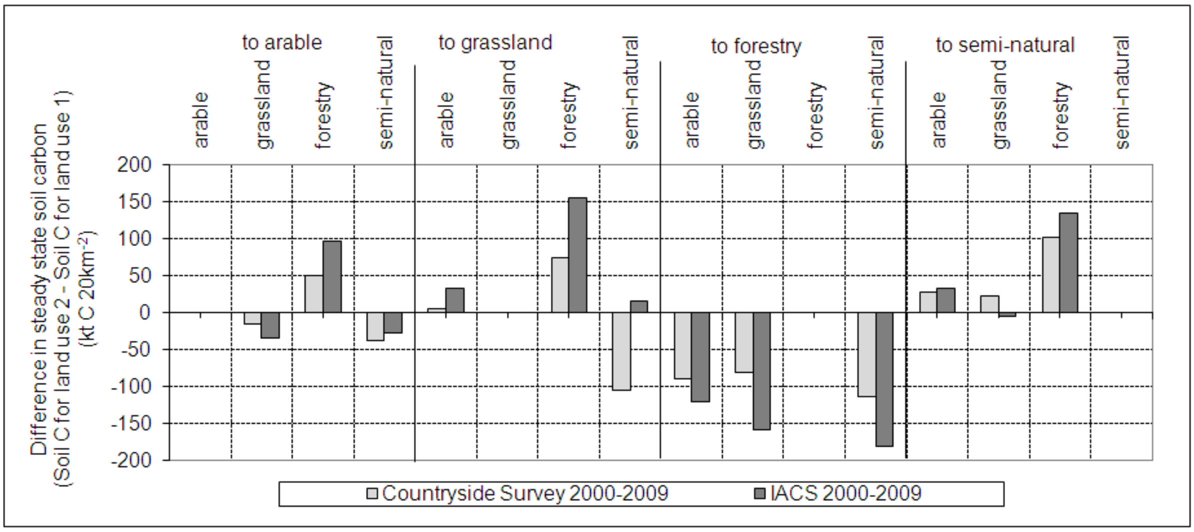


Figure 4.17 Area weighted average across Scotland of the difference between the steady state soil C contents of the top layer of soil under land use 2 and land use 1 for the soils recorded as having land use change from land use 1 to 2 and sufficient valid data to allow the land use change to be simulated in ECOSSE. Soils information is presented for the Countryside Survey and IACS simulations as indicated in the legend.

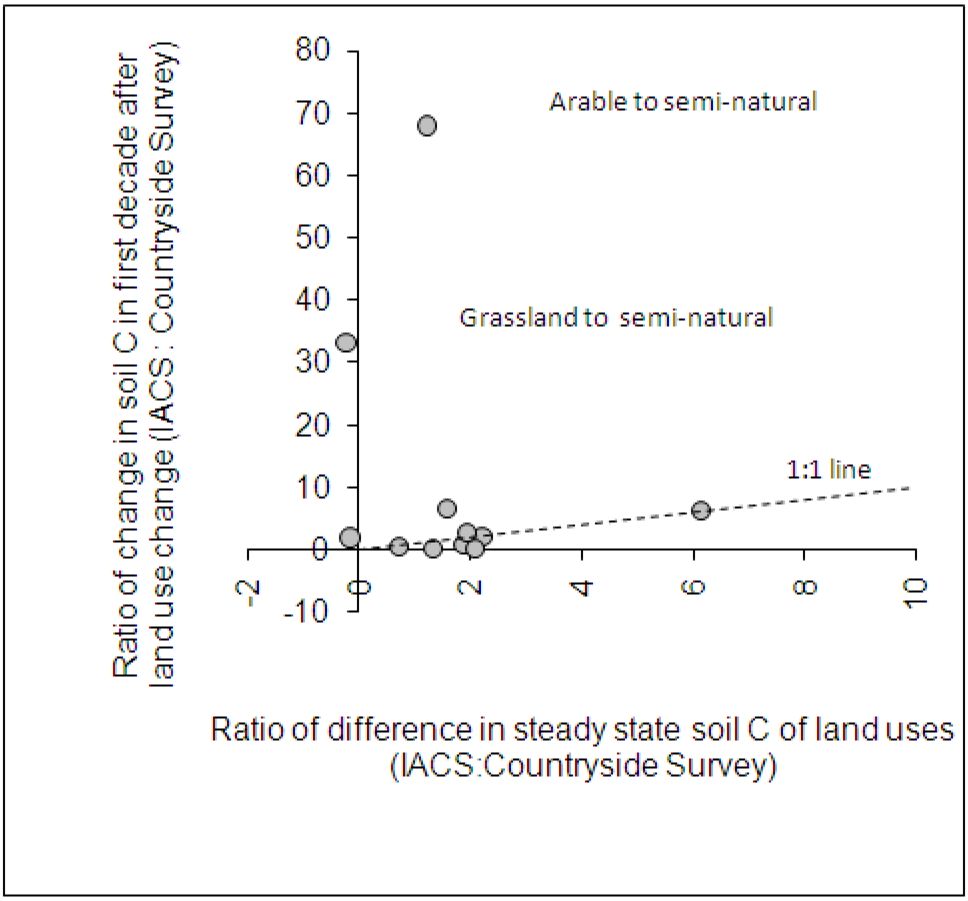
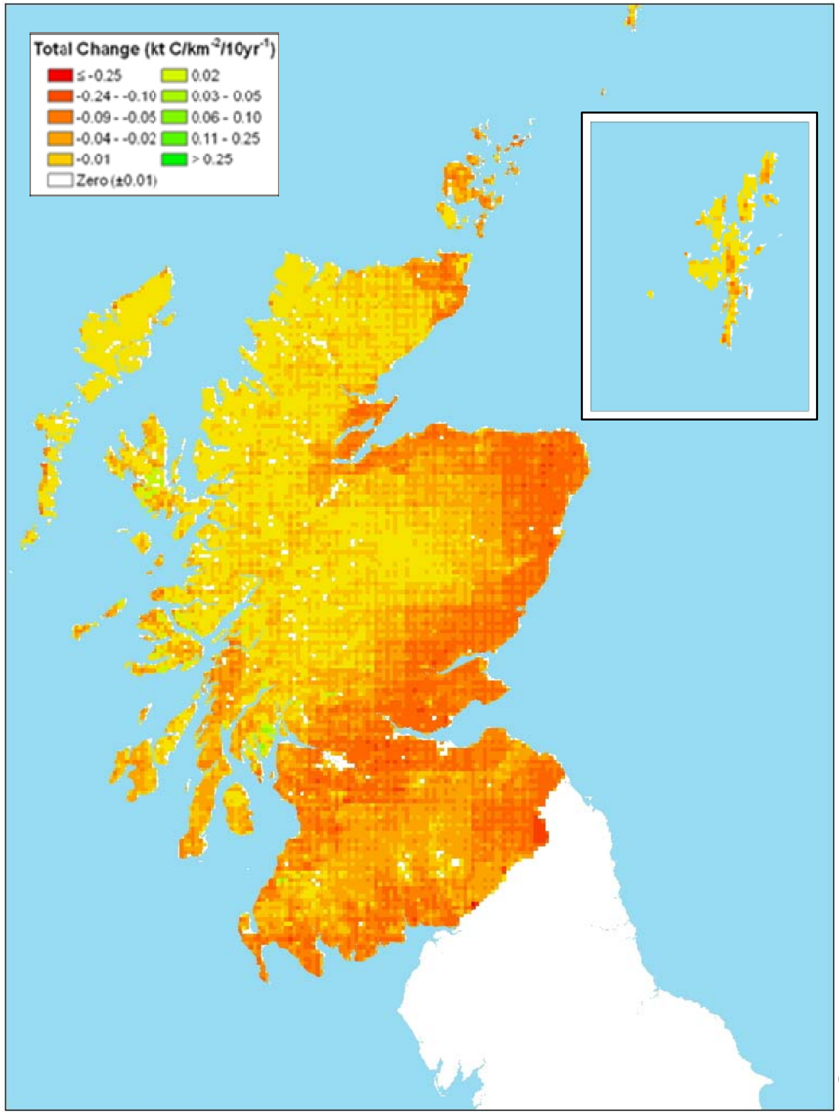


Figure 4.18. Ratio of the change in soil C in the first decade after land obtained using IACS and Countryside Survey data plotted against the ratio of steady state soil C obtained from the two data sources

Figure 4.19 shows the map of the total change in soil C across Scotland as simulated using Countryside Survey and IACS data. These maps illustrate the greater resolution in the simulations available using the IACS data. Direct comparison of the results at the same resolution is shown in Figure 4.20. The results simulated using IACS data show much greater spatial variation than the results simulated using Countryside Survey data, but broadly similar overall patterns of soil C change are observed. However, it can be seen that the green area over the West of the Country, predicted using Countryside Survey data is largely missing from the simulations using IACS data. This accounts for the larger overall net losses of soil C observed using IACS data, Figure 4.21 shows the map of change in soil C from the land use change grassland to arable as simulated using Countryside Survey and IACS data.

Figure 4.19 Total change in soil C across Scotland as simulated using (a) Countryside Survey (resolution = 1km grid) and (b) IACS data (resolution = 10m grid) from 2000-2009



(a)

(b)

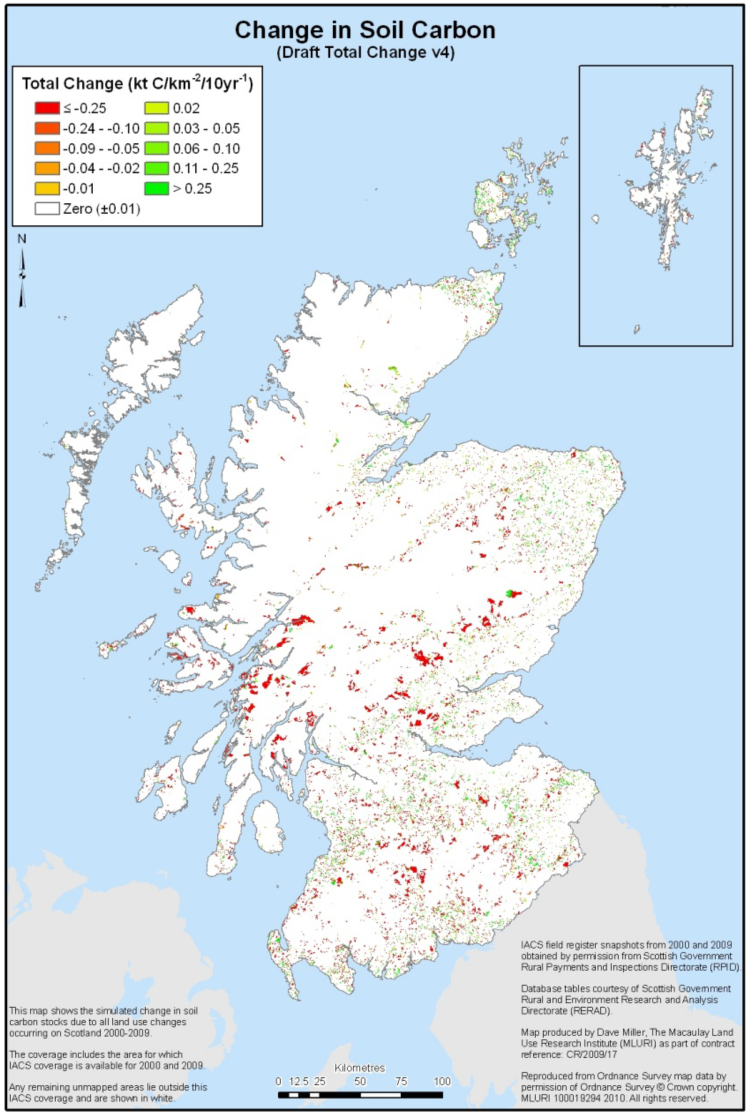
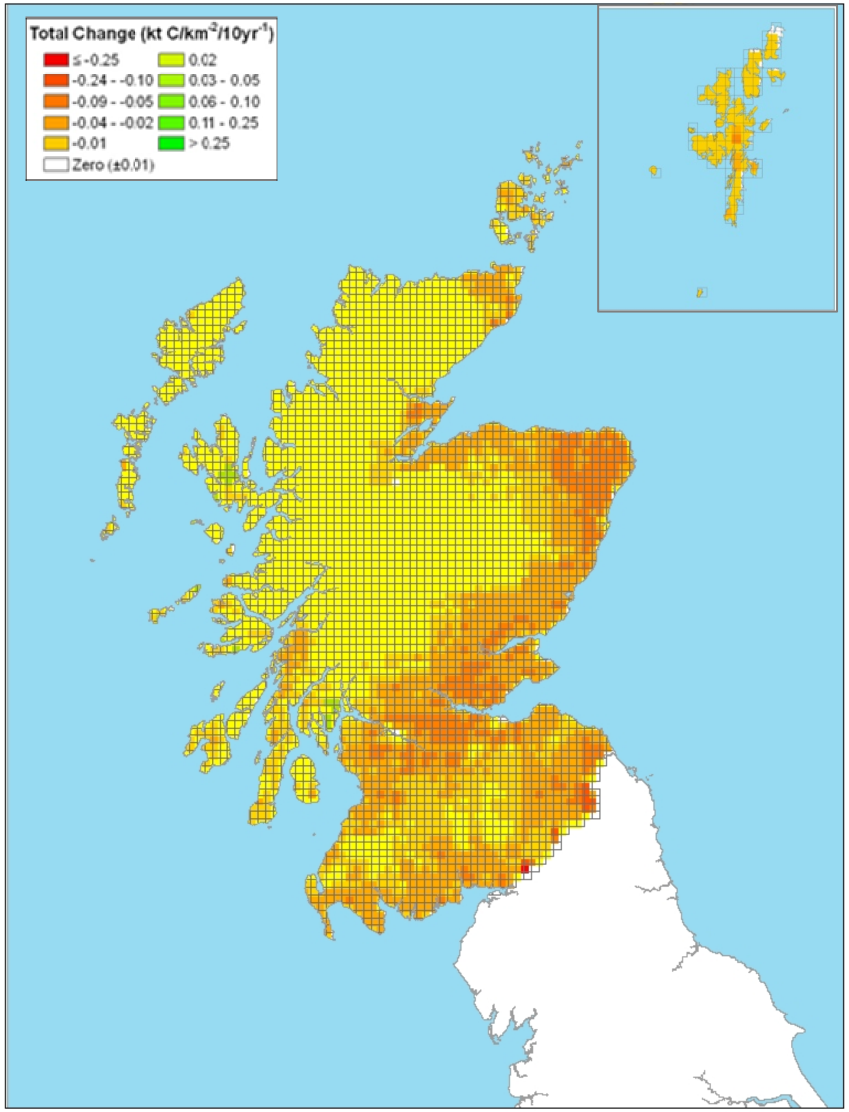


Figure 4.20 Total change in soil C across Scotland at 5km grid resolution as simulated using (a) Countryside Survey and (b) IACS data from 2000-2009



(a)

(b)

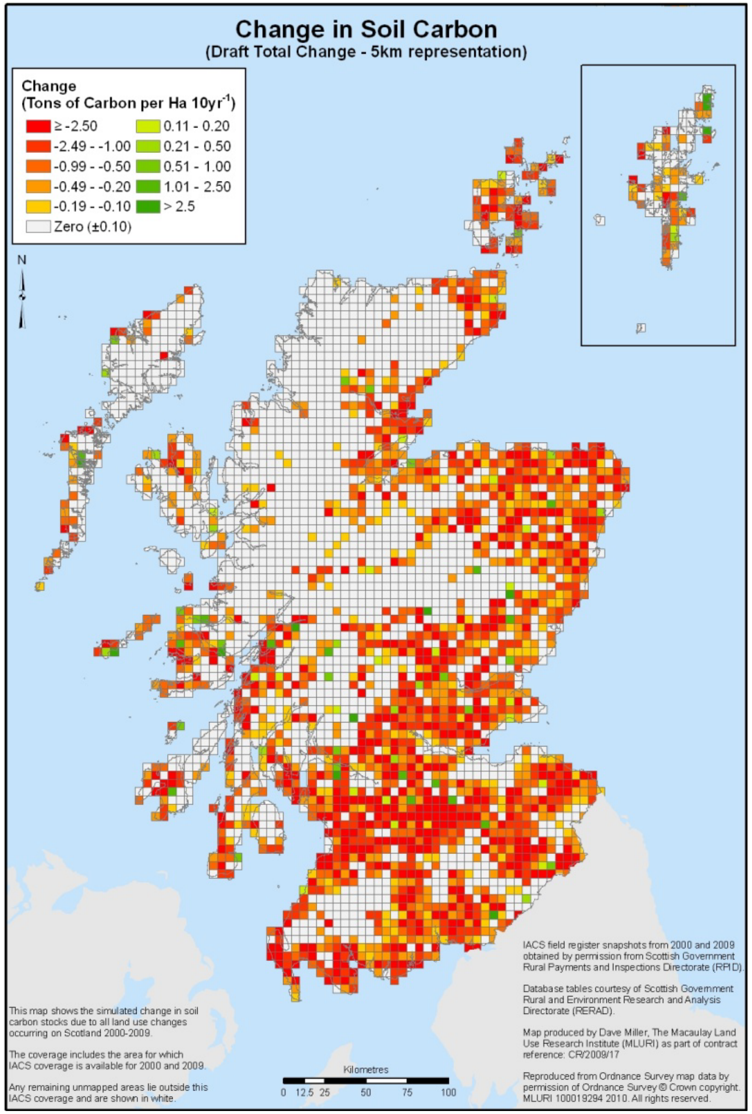
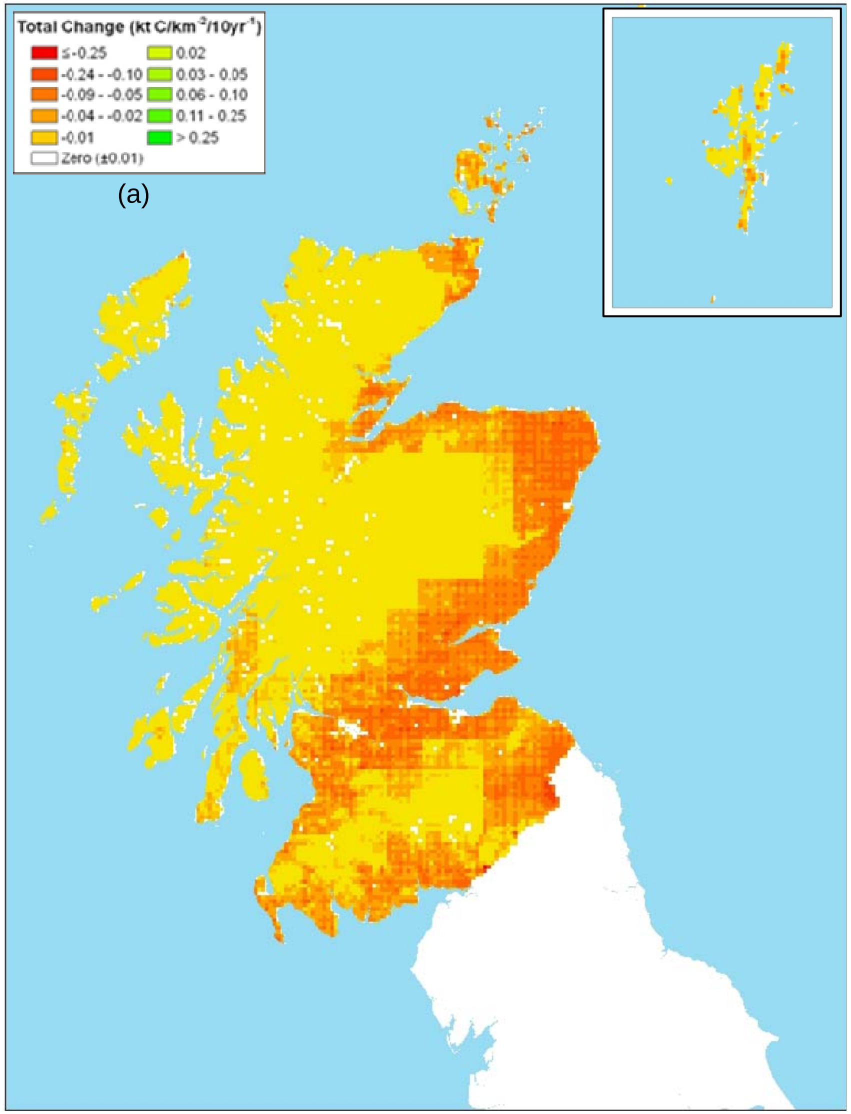
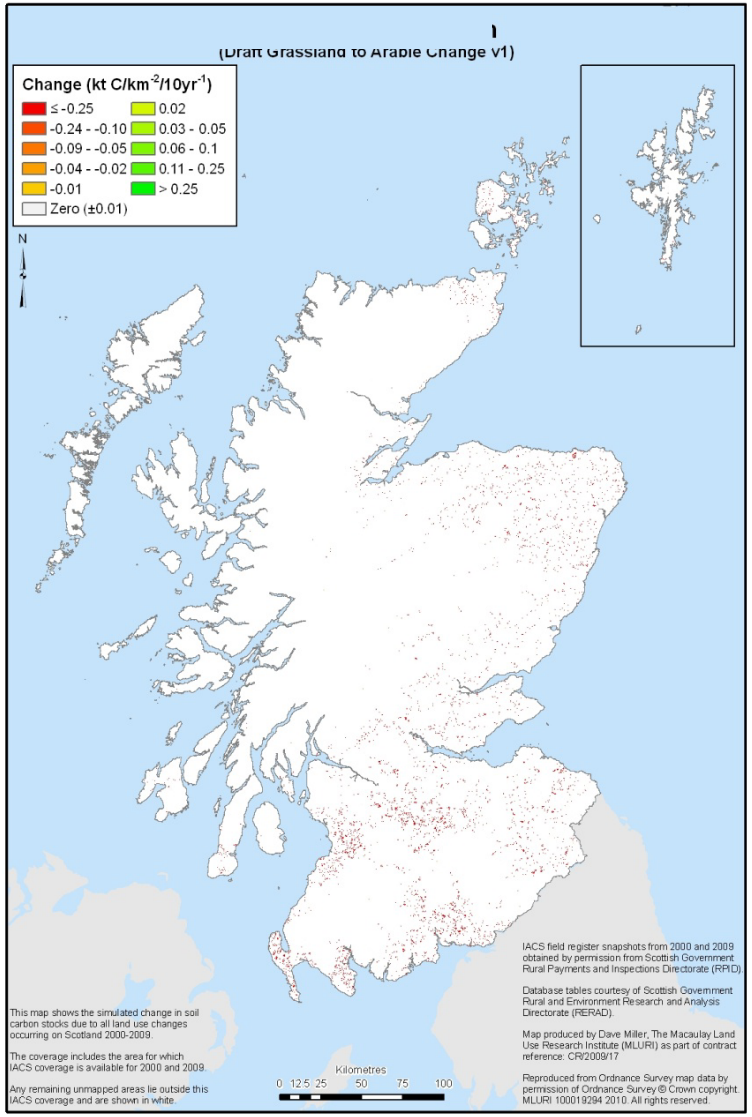


Figure 4.21 Maps of change in soil C from the land use change grassland to arable as simulated using (a) Countryside Survey and (b) IACS data from 2000-200



(a)

(b)



Figures 4.12 and 4.13 illustrated the difference between the areas of land use change recorded in the IACS and Countryside Survey, and the areas actually simulated by ECOSSE. Figures 4.22 and 4.23 show the relationship between the simulated and measured areas of land use change given by the Countryside Survey and IACS respectively, and shows that the correlation between simulated and measured land areas for Countryside Survey is extremely low (R^2 = 6%), whereas for IACS it is much higher (R^2 = 75%). If the grassland to semi-natural land use change is omitted, the R^2 value increases for the IACS land use change data to 93%. The reason for the land use change not being simulated in 61% of cases is due to soils data for the land use being missing, i.e. the land use change data is suggesting that land use changes occur on soil types where the land use is not normally practiced. This is reflected in an absence of data for soil characteristics relating to the particular land use on the given soil type. Using the land use change data provided by the Countryside Survey, this mismatch of land use change and soil type occurs more often than in the higher resolution IACS data, and this is reflected in the higher R^2 value obtained for the IACS data. This further supports the assertion that the IACS data provides a more accurate representation of land use changes that occur than the Countryside Survey.

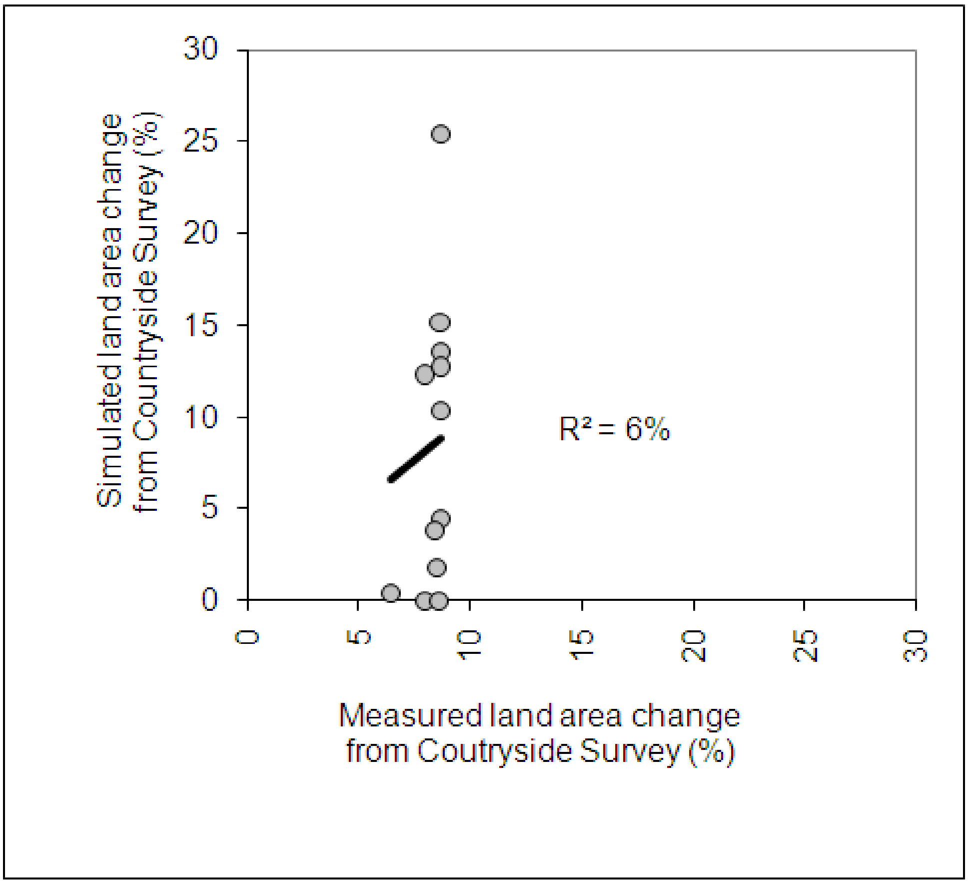


Figure 4.22 Correlation between the simulated and measured areas of land use change given by the Countryside Survey

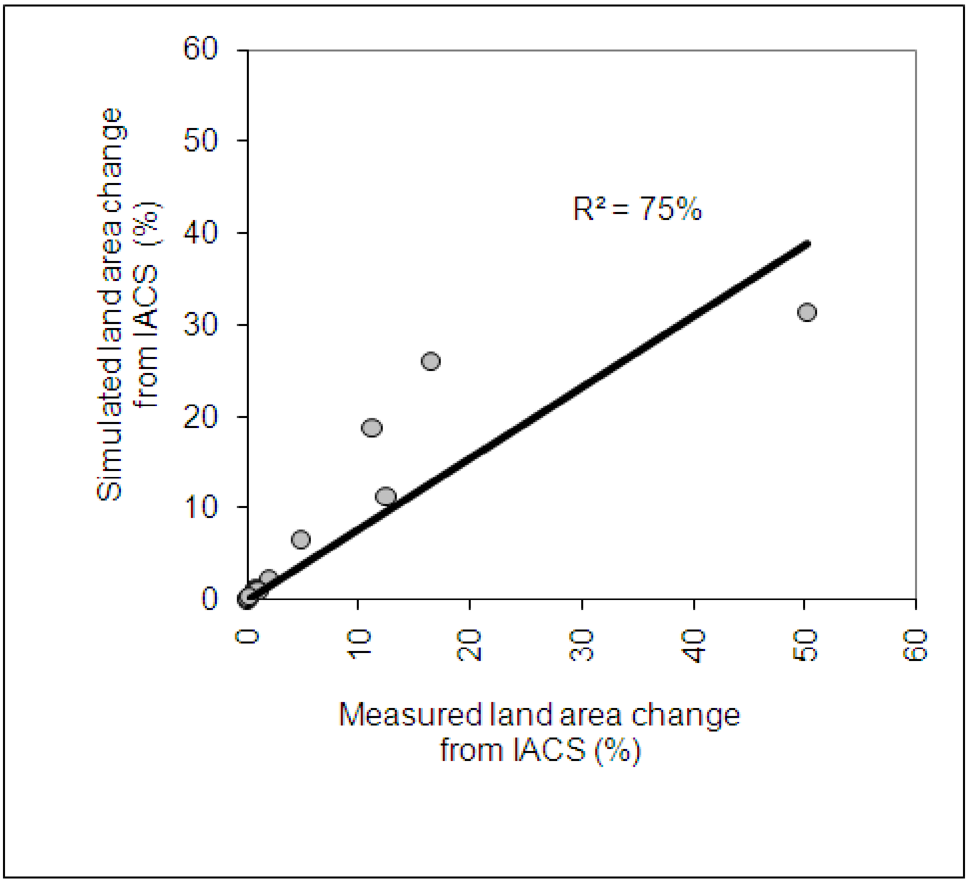


Figure 4.23 Correlation between the simulated and measured areas of land use change given by the IACS

4.2.3 Conclusions from ECOSSE simulations

The protocols for processing IACS data for use in ECOSSE and interpretation of the results produced have been established to allow easy rerun of simulations using IACS data that becomes available in future years. The data provides information at a finer scale than was previously possible with the Countryside Survey and includes more refined information on land use and management. In order to make full use of the detail in land use data, further ECOSSE land use categories and more refined soil characteristics data would be required, but the new protocol allows increased resolution of simulations to be achieved without further development.

The results obtained using IACS data were compared to the results obtained using land use change data from the Countryside Survey. A large increase in soil C losses is simulated using IACS data, especially from land use changes grassland to arable and grassland to semi-natural compared to the simulations using Countryside Survey data, resulting in a 228% increase in the total losses from soil C across Scotland. This increase in the simulated losses of soil C may in part be attributed to changes in farmer classification of land use as grassland or semi-natural associated with changes in area payments. When grassland and semi-natural land are considered as a single group, the increase in soil C losses is reduced from 228% to 66%.

Differences in land use change recorded in the Countryside Survey and IACS data account for 80% of the observed differences in soil C change. Improved resolution of data possible with the IACS data accounts for the remaining difference in the result.

4.3 Comparison of CEH GHG Inventory and ECOSSE calculations

The CEH GHG Inventory estimates of soil C losses in 2010 using IACS data from 2000-2009 are presented in table 4.11. The ECOSSE simulations of soil C losses in 2010 using IACS data from 2000-2009 are given in figure 4.15, Figure 4.24 shows the ECOSSE simulated values plotted against the CEH GHG Inventory estimates (multiplied by 10 to give the change in soil C per decade), combining grassland to semi-natural into a single group, because as discussed in section 4.2, errors could be introduced by possible changes in farmer classification of grassland and semi-natural land. The ECOSSE simulations are highly correlated with the estimates of soil C change provided by the CEH GHG Inventory ($R^2 = 0.84$). The correspondence between the changes in soil C estimated by the two different methods gives confidence in the results, but note that the high value for land use change grassland to arable largely controls the agreement between the two approaches. Note also that if the grassland to semi-natural land uses are included as separate groups, the correlation has an R^2 value of only 0.16

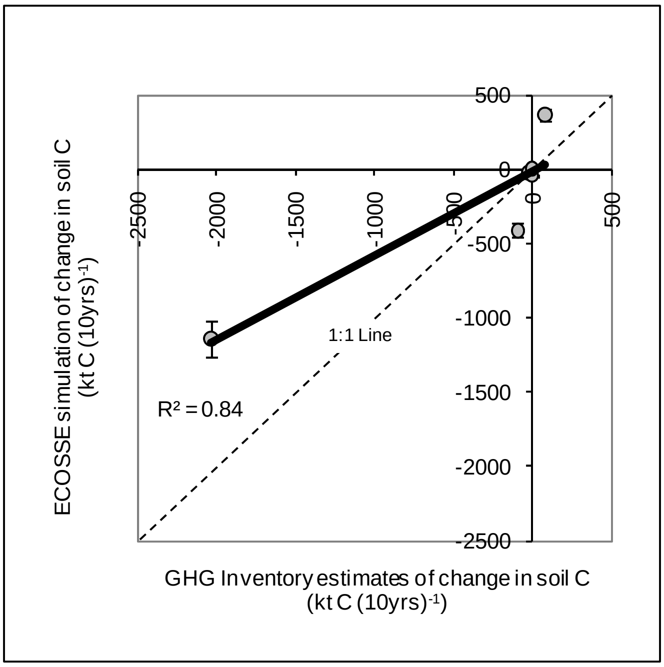


Figure 4.24 ECOSSE simulations of change in soil C in 2010 due to land use changes recorded in IACS database for 2000-2009 plotted against comparable estimates from the CEH GHG Inventory. Estimates for grassland to semi-natural are excluded due to uncertainty in the land use change data associated with changes in the classification of grassland and semi-natural land.

If the semi-natural and grassland land use types are combined, the higher resolution of the data provided by IACS results in a 66% increase in the soil C losses simulated by ECOSSE in the first decade, but only a 2% increase in the CEH GHG Inventory simulations compared to the ECOSSE simulations using Countryside Survey data. This difference is due to the way that the two approaches deal with the dynamics of soil C turnover. As shown in figure 4.25, ECOSSE simulates larger losses than the CEH GHG Inventory on conversion of grassland and semi-natural land to arable, but smaller gains on conversion of arable to grassland and semi-natural. Over the longer term, these differences will be reduced as the plant communities simulated in ECOSSE reach maturity and the soil recovers from cultivation losses.

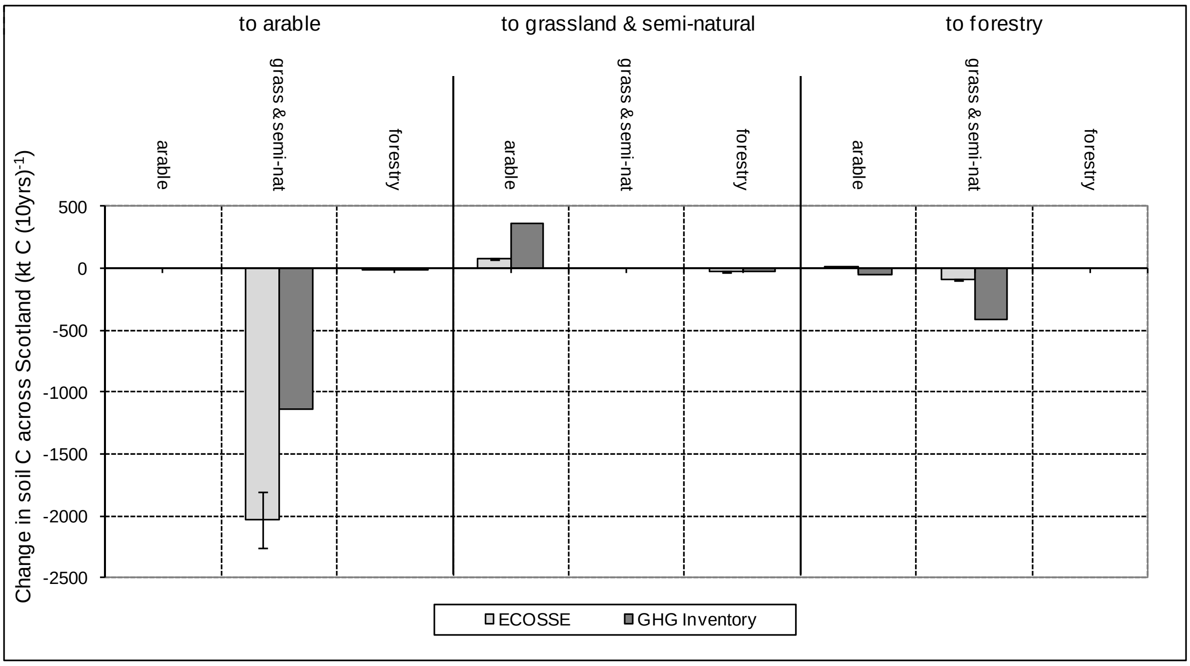


Figure 4.25 Total changes in soil carbon across Scotland between 2000 and 2009 calculated by ECOSSE and the CEH GHG Inventory as indicated in legend, using IACS land use change data from 2000-2009 only. Error bars represent the 11% uncertainty in national calculations estimated by Smith et al, 2009 for ECOSSE. Total losses of soil C simulated by ECOSSE are 63% greater than those estimated by the CEH GHG Inventory method.

4.4 Availability of soils data at scale of IACS

Providing soils data at the field scale, as used in IACS, would require additional soil series to be added to the SSKIB dataset used in previous ECOSSE model runs[1], which used a restricted soil series dataset associated with 1:250,000 scale soil mapping. More detailed 1:25,000 scale soil mapping is much more appropriate where field by field land cover/use data such as IACS are being used. An assessment of the effort required to generate soils data at this finer resolution is described in section 5.3.

4.5 Summary – implications to estimates of annual GHG emissions of different methods used in producing an assessment of agricultural land use change

The results obtained using IACS data were compared to the results obtained using data from the LULUCF databases for the CEH GHG Inventory and data from the Countryside Survey for ECOSSE. The resolution of the simulations using IACS data is finer than those using LULUCF or Countryside Survey data, and so allows more accurate determination of the interactions between soil type and land use change. However, there is some question over the stability of the land use classifications provided by farmers because the definition given is influenced by the changing nature of payments farmers receive. This is especially true for the classification of grassland and semi-natural land use, resulting in a large apparent conversion of grassland to semi-natural being recorded by IACS 2000-2009.

If the semi-natural and grassland land use types are combined, the higher resolution of the data provided by IACS results in a 66% increase in the soil C losses simulated by ECOSSE in the first decade, but only a 2% increase in the CEH GHG Inventory simulations compared to the ECOSSE simulations using Countryside Survey data. This difference is due to the way the two approaches deal with the dynamics of soil C turnover.

Differences in the areas of land use change recorded in the Countryside Survey and IACS data account for 47% of the observed differences in soil C change. When all land use changes from forestry and from semi-natural to arable land are excluded from the analysis, this value increases to 78%, implying that for these land use changes, it is the improved resolution of soils data possible with the IACS data accounts for the difference in the result.

IACS data are likely to be more representative of farm industry land use than the Countryside Survey data and using it in combination with fine scale soil series data is likely to provide improved soil carbon density estimates. IACS data are potentially available annually, which will improve the temporal as well as the spatial resolution of GHG emission estimates. However, IACS data does not cover all of Scotland with 42% of land in 2000 missing due to land not being included in a farming business. Therefore higher resolution data on forestry and semi-natural land use categories would be needed to increase coverage for the whole of Scotland.

5. Availability of soils data

Phase 3 focuses on the availability of soils data, particularly for the LU categories semi-natural and forestry. Limitations in the availability of data for afforested soils have been identified at the 1km^2 scale in recent RERAD funded projects[1,2]. A number of new sampling initiatives, especially under forested soils, have potential to improve the quality of data available at this scale. Following on from recommendations made in previous reports[1], the feasibility of accessing archived but non-digitised data on forest soils has been examined. These sources have been reviewed and the potential to improve the estimates of soil C content under forestry land assessed. This work contributes to the objective to critically assess the current LULUCF inventory and determine how underlying soils data for LU categories important for Scotland such as semi-natural and forestry could be better represented.

5.1 Review of soils data available in Scotland

Previous estimates of changes in soil carbon due to land use change using the ECOSSE model identified potential limitations in the current approach to providing input data for afforested soils. In short, and following precedent, the morphology of afforested soils was created by adding an LF horizon to those horizon sequences identified for moorland soils within the SSKIB (Scottish Soils Knowledge and Information Base) dataset. This has the effect of almost always increasing the carbon content of afforested soils in the upper 1m over which ECOSSE simulations are run. There is evidence to suggest that this increase is not necessarily true in the short term (ECOSSE 2 report for summary) due to disturbance and draining of some soils during the planting phase. Clearly there is a need for more robust data on afforested soils.

The relative lack of soils information for afforested soils within the Scottish Soils Database is primarily due to the historic development of the Soil Survey of Scotland. Early mapping and data collection was mainly concerned with cultivated, agricultural soils. This means that there is a relative lack of good quality information on the distribution and amounts of C in afforested soils.

In order to address the requirements of land use and climate change models, further data collection on a substantial scale would be required. This could include further soil sampling of afforested soils following NSIS protocols, further sampling using less complicated protocols, data mining from existing soils datasets (NSIS, Scottish Soils Database, Biosoil) to augment SSKIB and aggregating existing soil data at higher levels (for example, at a major soil subgroup level rather than soil series level).

This project aimed to address the third approach; assessing the scope for determining the morphology and C concentrations of afforested soils from existing soils data. This project does not set out to determine the carbon contents of afforested Scottish soils, but rather to establish whether there is potential for enhancing the SSKIB dataset from existing data.

5.2 Improvement of soils data under forestry

5.2.1 Data from within the Scottish Soils Database

There are around 870 soil profiles within the Scottish Soils Database that have a woodland vegetation ranging from broadleaved, birch scrub to commercial, high density conifer plantation. Of these, around 300 are under coniferous woodland including Scots Pine. Approximately 440 are designated only as ‘Woodland’ and the site and profile characteristics are not held electronically.

In terms of updating the SSKIB dataset, which is based on Soil Series, of these 870 profiles; 31 have no soil series recorded; there are 120 different soil series represented of which, about 40 have less than 3 profiles. SSKIB comprises 530 unique Soil Series so it is clear that it is not possible to fully update SSKIB for afforested soils from these additional data alone. However, this is also true for other land uses. In these cases SSKIB has analogous soils, that is, the missing data are derived from soils with similar physical and chemical characteristics; part of the 'knowledge' component of the Scottish Soils Knowledge and Information Base. Even so, there does appear to be insufficient data to fully establish data for all Soil Series that are likely to be afforested.

Another possible approach is to aggregate the profiles at the Major Soil Subgroup level (MSSG). Table 5.1 shows the soil type and number of available profiles with a woodland vegetation type. However, as there are 28 MSSG represented within the SSKIB dataset, there is a shortfall in the number of MSSGs represented by the 870 woodland profiles (12 MSSGs with >3 profiles compared with 28 MSSGs in SSKIB) although 8 of the MSSGs represented within SSKIB are unlikely to be afforested (for example, Lithosols, Alpine and Subalpine podzols). The remaining missing MSSGs are of relatively minor extent as are the soils with 3 or less profiles.

Table 5.1 The number of soil profiles in each Major Soil SubGroup under Woodland

Major Soil SubGroup	**Number of profiles**
Mineral alluvial soils	14
Brown podzol	53
Brown earth	132
Brown earth with gleying	55
Iron podzol	38
Humus iron podzol	211
Noncalcareous gley	74
Humic gley	34
Peaty gley	90
Peaty podzol (and peaty gleyed podzol)	55
Peat (blanket and basin)	62
Not recorded	31
Anthrosols	2
Brown calcareous	2
Brown ranker	2
Magnesian gley	2
Noncalcareous regosol	6
Regosols	3

There are also around 3700 profile descriptions within the Scottish Soils Database for which no vegetation has been recorded in the database but which has been recorded as part of the profile description and held in hard copy format. Around 1200 of these are from a specific grid survey of an upland farm that had no woodland vegetation. However, the remaining 2500 may well contain descriptions of soils under woodland, and, again, any relevant analytical data relevant for carbon modelling are already in electronic from (though about 8% of these have no analytical data). In order to assess the likely number of these profiles that are from soils under woodland, 250 (10%) were randomly selected and the hard copy card extracted from the filing system. This took just under 2 hours so it would take about 20 hours or 3 person days to extract all 2500 cards.

Of the 250 randomly selected, 47 could not be found (they are perhaps stored elsewhere and need to be located) of the remainder, 20 had woodland vegetation (8.8%) suggesting that there could be an additional 220 profile descriptions of soils under woodland (assuming that there is proportionality in the number of cards not found). Around 7% of these 2500 profiles had no analytical data; however, they could be used to determine the horizon sequences and depths for afforested soils. It is estimated that a further 15 man days would be required to extract the horizon sequence and depth data from all of these 2500 profiles and enter them into the database and approximately 5 days to extract only the data relevant to afforested soils (including the need to manually retrieve 2500 cards initially). An additional day would be required if information of type of woodland was to be extracted also and the number of days necessary to extract additional morphological and site data could double the amount of time required.

Thus it is estimated that there are around 1,000 soils profiles within the Scottish Soils Database that are from soils under woodland and are held as hard copy profile descriptions. It would require between 7 and 15 days to locate, extract and enter the required data into the database. The vast majority of these profiles are pre-1983.

5.2.2 Other sources of data

Other sources of soils data are available outside of the Scottish Soils Database and include 67 soil profiles sampled during the BioSoil project and between 200 and 300 soil profile descriptions with analytical data from Forest Research (Bill Rayner, *pers comm*).

The BioSoil project carried out by Forest Research in the UK is a demonstration project of the International Cooperative Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (http://www.icp-forests.org/). The soils from those woodlands that intersected a 16x16km grid across Scotland (and the rest of Europe) were described and sampled in a similar process to the NSIS. Although samples were taken at fixed depths (unlike NSIS), bulk density measurements were taken, and the soil carbon content was measured. These profile descriptions would also provide additional information on the horizon sequences of soils under woodlands. While the soil profile description cards held by MLURI are typed, the additional soil profiles held by Forest Research are hand written and comprise profiles taken from peats, organo-mineral and mineral soils from Forestry Commission land throughout Scotland. No estimate of the time likely to be involved in transferring even the basic data (eg, horizon sequence) has been made. As many of these profiles are likely to be from pre-panting phase also, it is difficult to establish exactly how many profiles will be relevant to updating input data for carbon models.

5.2.3 Determination of typical horizon sequences

One of the issues with the data derived for afforested soils used in ECOSSE (Smith et al, 2009) was whether the addition of an LF horizon fairly reflected the actual profile horizon sequence of these soils. Although the analytical data of all 870 profiles with woodland vegetation within the Scottish Soils Database are held electronically, not all horizons were sampled. This means that there may well be additional surface (eg LF) or thin horizons for which we have morphological data which is only recoded in the paper records. Therefore there is additional information of the horizon sequence that is available on these hard copy profile description cards. It would be prudent to examine these profiles and to record the actual horizon sequences to assess if soils under woodland develop LF horizons or if this is only a feature of certain soils (perhaps influenced by the MSSG).

Data were extracted from the Scottish Soils Database where the soil profiles were under woodland vegetation and had limited (or ‘partial’) contextual data and no morphological data stored electronically. This selection yielded 435 soil profiles. In order to assess the feasibility of extracting the original profile description cards and transcribing the required information to electronic data storage, 50 profiles were randomly selected from the list (approximately 10%). In the past, attempts had been made to capture some of the contextual information from these cards, for instance soil type, series, association, altitude and the horizon nomenclature of the sampled horizons had been updated. In order to create a coherent dataset, it is proposed that the existing information for each of these profiles should be augmented by additional morphological data, especially the full horizon sequence. Retrieval of these 435 profile description cards should take no more than 1 person day. However, the extraction of some of the morphological data will require expert knowledge in many cases. It is expected that this could take up to 5 person days. A restricted set of morphological features may be obtained by competent staff and take around 3 days (plus retrieval time).

5.3 Identification of further work needed to improve soils data to match IACS data

The available soil maps that most closely match the scale of the IACS data are the 1:25,000 scale Soil Series maps. These maps cover around 95% of the cultivated land in Scotland. The SSKIB dataset was deliberately aligned with the broader 1:250,000 scale soil map. At this scale, Soil Series of minor extent could not be delineated. Thus the number of Series depicted on this map (and therefore form part of the SSKIB dataset) is less than the number of Series that were mapped at the more detailed 1:25,000 scale (530 Series in SSKIB and 800 Series recognised in total plus 275 Complex mapping units). Thus it is clear that there are currently insufficient data within SSKIB in order to match the resolution of the IACS data and, if changes in carbon content due to land use and climate change are to be modelled, the data for the 'missing' Series need to be extracted and summarised to augment SSKIB. In order to gauge how much effort this was likely to be, a pilot project was undertaken using the Tarland Catchment as an example.

The 1:25,000 scale soil digitised soil map of the Tarland Catchment was intersected with the 1:25,000 scale LCS_88 land cover map to establish the component Soil Series and whether the soil was cultivated or still in a semi-natural state.

A total of 6 Soil Series (both cultivated and semi-natural phases) were identified as being in the Tarland Catchment but not in SSKIB while a further 5 Soil Series were present in SSKIB but only as the uncultivated or semi-natural phase. Another 4 soils had direct comparisons within SSKIB and another map unit had no direct Soil Series equivalent.

It took around 12 hours to establish a typical horizon sequence for the missing soils, to calculate summary information such as means, standard deviation etc as in the SSKIB dataset, to check and fill in missing data using detection limit values where appropriate and to calculate derived properties such as Organic Matter content and Base Saturation. This equates to 1.2 hours per Soil Series where data was available. With approximately 270 Soil Series not in the SSKIB dataset the time to collate the soil information needed to match the scale of the IACS data is just short of 45 working days. However, from experience with the Tarland catchment data, not all Soil series will have sufficiently good quality data to provide estimates of the SSKIB summary statistics and (as with the SSKIB dataset itself), data will have to be found from analogous Soil Series in order to complete the dataset. This is unlikely to add much time to the overall assessment as time saved by not calculating summary statistics can be used to identify analogues.

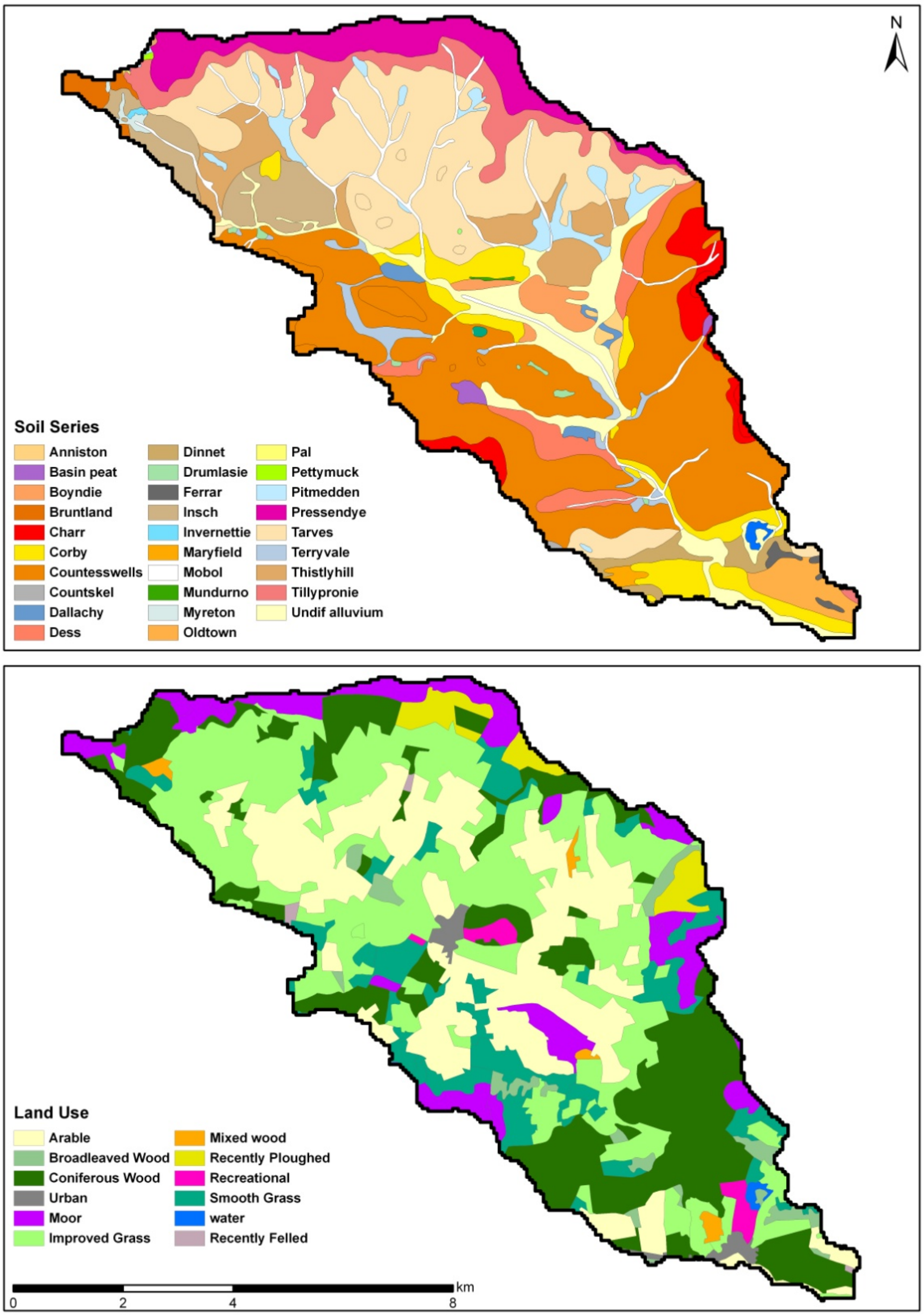


Figure 5.1 Soil and Landcover maps of the Tarland Catchment

5.4 Summary - implications to estimates of annual GHG emissions of improvements in soils data

There are a range of options to identify and update the required input data for C modelling. This varies from augmenting a minimal dataset that is partially available to extracting all the relevant horizon sequence, depth and morphological data from 3370 soil profiles (870+ 2500). As there are varying degrees of data already available, it is not a simple linear relationship between effort required and data collated. Table 5.2 presents a summary of options and time required. The time required may vary depending on the level of expertise of the staff involved in interpreting soil profiles.

Table 5.2 Estimated time to extract and collate existing soil data from the Scottish Soils Database.

Options	Profiles (n)	Time (person days)
Option1	870 (330 are already available)	4
Option2	Option 1+220	9
Option3	Option1+2500 (horizon sequence and depth only)	17
Option 4	Option 1+2500 (all available morphological data)	51
Additional		
Biosoil	67	1-2 days (estimated)
Forest Research	200-300	unknown

In summary, it is likely that there are insufficient soil profiles to provide summary data for all soil series even excluding those unlikely to be afforested. Calculating horizon sequences, depths and summary data at the level of major soil subgroup (mssg) also may not provide the required data but the main mssgs are likely to be represented. There are a number of soil profiles for which analytical data is available in electronic format but where the vegetation type has not been transferred from profile cards to the database. There are a number of options for capturing these data (Table 5.2) which could be readily implemented. Once the data mining of the Scottish Soil Database has been exhausted, additional data sources can be explored. Of these, the Biosoil dataset offers the most cost effective additional data while the Forest research soil profile data would require further exploration to determine both the value and time required to extract the data. Once these options have been exhausted, gaps in the data can be filled by targeted soil sampling.

6. Future work

IACS data has great potential to produce improved estimates in terms of spatial resolution and frequency of updates for the GHG emissions inventory for Scotland on an annual basis for the land use sector. The improved resolution of the data is likely to increase estimates of losses in soil carbon by as much as 66%. Problems with classification creep will be resolved as land use categories become more established. This could also be achieved by accounting for land use in successive years; for example, if land use semi-natural changes to grass>5years, the new land use should be defined as semi-natural, whereas if land use grass<5 years changes to grass>5years, the new land use should be defined as grassland. Greater specificity in land use and management options could be achieved by expanding the land use classes to correspond to the IACS classifications, rather than reducing the IACS classifications to match those existing in ECOSSE and the CEH GHG Inventory. However, this would require soils data to be divided into the same land use classes, which is not currently feasible given the availability of soil measurements. There might be scope for some form of half-way house with a more detailed list of land use classes than those used in ECOSSE but rather fewer than the full IACS listing. Many of the latter in the cropping category may only persist for a year and land uses changes between them would not be meaningful. It is within the other categories (grassland, forestry, semi-natural), which have fewer IACS land use descriptions, where more meaningful carbon transitions occur. To go further, a break-down of “Woodland and forestry” into broadleaf vs coniferous or natural vs plantation would have more implications than moving from peas to beans. However, there remains the problem of whether the soils data can match any further dissection.

There is clearly scope for improving the climate data. Greater resolution is unlikely to appear in the near future but it should be possible to add in those areas where coverage in currently incomplete.

In order to improve the coverage of land use data for Scotland, integration of IACS with the National Forest Inventory and other Forestry Commission data on afforestation and deforestation should be a priority, Changes in urban (i.e. Settlements) land use will also need to be considered. OS Mastermap should be investigated as a source of information on urban land as its data are updated regularly to meet the needs of development planning. OS Mastermap may also be a source of information on rural land not included in IACS or Forestry Commission data but updates for these areas may actually occur less often than by the Countryside Survey.

7. Conclusions

IACS data

IACS data provides extensive, high resolution land use change data across Scotland. The most significant limitation in IACS is the forestry cover which is under represented with less than 30% of Scotland's woodland being mapped. There is also semi-natural and developed land that is not included in IACS but is required to be included in UNFCCC GHG Inventories. IACS is the only spatial LU dataset updated on an annual basis. Protocols for access to IACS data for research use and for translation of the data into input files for ECOSSE and the CEH GHG Inventory have been established and work well. Unique combinations of LU, LUC, soil, climate and previous LU change are identified using LU and soils data at a 100m grid resolution, and climate data at a 5km grid, so increasing the resolution from 20km grid to 5km grid.

Limitations of the IACS dataset include the problem of classification reliability and creep. From 2009 there is a commitment to the collection of the land use classes required by the JAC and these are more than sufficiently specific for the current requirements of the ECOSSE and CEH GHG Inventory. There is, however, the need for care in interpreting annual change in land use, especially for land uses near the boundaries of classes, such as grassland and semi-natural, where classification may change in response to other drivers such as SFP cross compliance criteria.

Implications to estimates of annual GHG emissions of improvements in land use change data

The resolution of the simulations using IACS data is finer than those using LULUCF or Countryside Survey data, and so allows more accurate determination of the interactions between soil type and land use change. However, there is some question over the stability of the land use classifications provided by farmers before 2009 because the definition given is influenced by the changing nature of payments farmers receive. This is especially true for the classification of grassland and semi-natural land use, resulting in a large conversion of grassland to semi-natural being recorded by IACS 2000-2009. Future data should have improved stability of classification due to the collection of land use classes required by JAC.

If the semi-natural and grassland land use types are combined, the higher resolution of the data provided by IACS results in a 66% increase in the soil C losses simulated by ECOSSE in the first decade, but only a 2% increase in the CEH GHG Inventory simulations compared to the ECOSSE simulations using Countryside Survey data. This difference is due to the way that the two approaches deal with the dynamics of soil C turnover. Differences in land use change recorded in the Countryside Survey and IACS data account for 80% of the differences observed in the soil C changes simulated by ECOSSE. The remaining differences are accounted for by the increased resolution of the IACS data. Over the long term, the ECOSSE model produces similar results for soil C stock change to the CEH GHG Inventory approach, but the dynamics of the simulations differ due to the detail of turnover processes included in ECOSSE. An earlier Scottish Government funded project (Smith et al, 2009) used National Soils Inventory data to estimate the uncertainty in the simulations of soil C stock change provided by ECOSSE to be 11%. As more data becomes available, the estimates of uncertainty in ECOSSE will be improved. Changes in biomass carbon are not dealt with here but are of significant importance in determining the net GHG emissions for Scotland due to the large areas of growing forest.

IACS data are likely to be more representative of the agricultural land use than the Countryside Survey data and using it in combination with fine scale soil series data is likely to provide improved soil carbon density estimates. IACS data are potentially available annually, which will improve the temporal as well as the spatial resolution of GHG emission estimates.

Implications to estimates of annual GHG emissions of improvements in soils data

There are a range of options to identify and update the required input data for C modelling. This varies from augmenting a minimal dataset that is partially available to extracting all the relevant horizon sequence, depth and morphological data from 3370 soil profiles (870+ 2500). It is likely that there are insufficient soil profiles to provide summary data for all soil series even excluding those unlikely to be afforested. Calculating horizon sequences, depths and summary data at the level of major soil subgroup also may not provide all the required data but the main soil subgroups are likely to be represented. There are a number of soil profiles for which analytical data is available in electronic format but where the vegetation type has not been transferred from profile cards to the database. Once the data mining of the Scottish Soil Database has been exhausted, additional data sources such as the Biosoils dataset and Forest Research soil profile data should be explored. Once these options have been exhausted, gaps in the data should be filled by targeted soil sampling.

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9. Appendix 1 – Land use classifications

Look up table – ECOSSE and CEH GHG Inventory (E&I) classes and IACS land use descriptions. The table includes all IACS land use descriptions used since 1994.

E&I Classification	IACS land use descriptions - all years
Unclassified	Land let out to others
	Normal setaside - own management plan
	Unclaimed land
Cropping	Arable silage for stock feed
	Aromatic, medical and culinary plants
	Artichokes
	Asparagus
	Beans for human consumption
	Beans for energy
	Bedding and pot plants
	Bilberries (and other fruits of the genus *Vaccinium*)
	Blackberries
	Blackcurrants
	Borage
	Brussel sprouts
	Buckwheat
	Buckwheat energy
	Bulbs/flowers
	Bulbs/flowers energy
	Cabbages
	Calabrese
	Canary seed
	Canary seed energy
	Carrots
	Cauliflower
	Cranberries
	Durum wheat
	Durum wheat energy
	Fallow
	Fibre flax
	Fibre flax energy
	Field beans
	Flower bulbs and cut flowers
	Fodder beet
	Gooseberries
	Grass under 5 years
	Hemp
	Hemp energy
	Kale and cabbages for stockfeed

E&I Classification	IACS land use descriptions - all years
Cropping (cont)	Leeks Lettuce Linseed Linseed energy Loganberries Maize Maize energy Millet Millet energy Mixed cereals Mixed cereals energy Mulberries Non-food setaside - barley for industrial use Non-food setaside – borage Non-food setaside - *Crambe* for industrial use Non-food setaside – hemp Non-food setaside - high erucic acid rapeseed Non-food setaside - linseed for industrial use Non-food setaside - oats for industrial use Non-food setaside - oilseed rape for industrial use Non-food setaside - other crops for industrial use Non-food setaside - outdoor plants Non-food setaside - potatoes for industrial use Non-food setaside - soya for industrial use Non-food setaside - wheat for industrial use Normal setaside - bare fallow Normal setaside - mustard Normal setaside - organic legumes Normal setaside - *Phacelia* Nurseries Nursery - fruit stock Nursery - ornamental trees Nursery - roses and rose stock Nursery - shrubs Oilseed rape Other crops for stock feed Other nursery stocks Other soft fruit Other vegetables Other vegetables energy Peas for human consumption Peas for energy Protein peas Rape for stock feed

E&I Classification	IACS land use descriptions - all years
Cropping (cont)	Raspberries
	Redcurrants
	Reed canary grass energy
	Rhubarb
	Rye
	Rye energy
	Seed potatoes
	Seed potatoes energy
	Shopping turnips/swedes
	Shopping turnips/swedes energy
	Soft fruit
	Soft fruit energy
	Sorghum
	Sorghum energy
	Spring barley
	Spring barley energy
	Spring oats
	Spring oats energy
	Spring oilseed rape
	Spring oilseed rape energy
	Spring wheat
	Spring wheat energy
	Strawberries
	Sweet lupins
	Sweetcorn
	Sweetcorn energy
	Top fruit
	Top fruit energy
	Triticale
	Triticale energy
	Turf production
	Turnips/swedes for stock feed
	Ware potatoes
	Ware potatoes energy
	Whitecurrants
	Whole crop cereals
	Wild bird seed
	Winter barley
	Winter barley energy
	Winter oats
	Winter oats energy
	Winter oilseed rape
	Winter oilseed rape energy

E&I Classification	IACS land use descriptions - all years
Cropping (cont)	Winter wheat
	Winter wheat energy
Grassland	Grass over 5 years
	Green cover mixture
	Land previously structural set-aside
	Miscanthus energy
	Normal setaside - green cover mixture
	Normal setaside - sown grass cover
	Setaside agricultural production - arable
	Setaside agricultural production - forage
	Setaside agricultural production - proteins
Forestry	Almonds
	Hazelnuts
	Non-food setaside - forest trees short cycle
	Non-food setaside - trees shrubs and bushes
	Normal setaside - 5 year under fws
	Normal setaside - 5 year under wgs
	Normal setaside - wild bird cover
	Open woodland(grazed)
	Pistachios
	Short rotation coppice
	Short rotation coppice energy
	Structural setaside - ex 5 year still in fws
	Structural setaside - wgs, fwps or sfgs
	Trees shrubs & bushes
	Walnuts
	Woodland and forestry
	Woodland/forestry with unique field identifier
Semi Natural	Common grazing
	LFASS ineligible environmental management
	Normal setaside - nat regen (after cereals)
	Normal setaside - nat regen (after other crops)
	normal setaside - next to watercourses, hedges, woods, dykes and SSSIs
	Positive environmental management
	Rough grazing
	Scree or scrub
	Sfps being claimed on agri-environmental options
	Shared grazing
	Structural setaside - eligible habitats
Other	Other land
	Ponds, rivers, streams or lochs
	Roads, yards or buildings

10. Appendix 2 – Implementation issues

Choice of soil map units

A soil map unit of 1:250,000 was selected (figure A.2.1). As illustrated below, in lowland areas a 1:250,000 soil map is not likely to be sufficiently detailed. A soil series map of 1:25,000 resolution would be more appropriate (figure A.2.2). However, the physical and chemical data needed to run ECOSSE or the GHG Inventory is currently not available for all the soil series included at this scale.

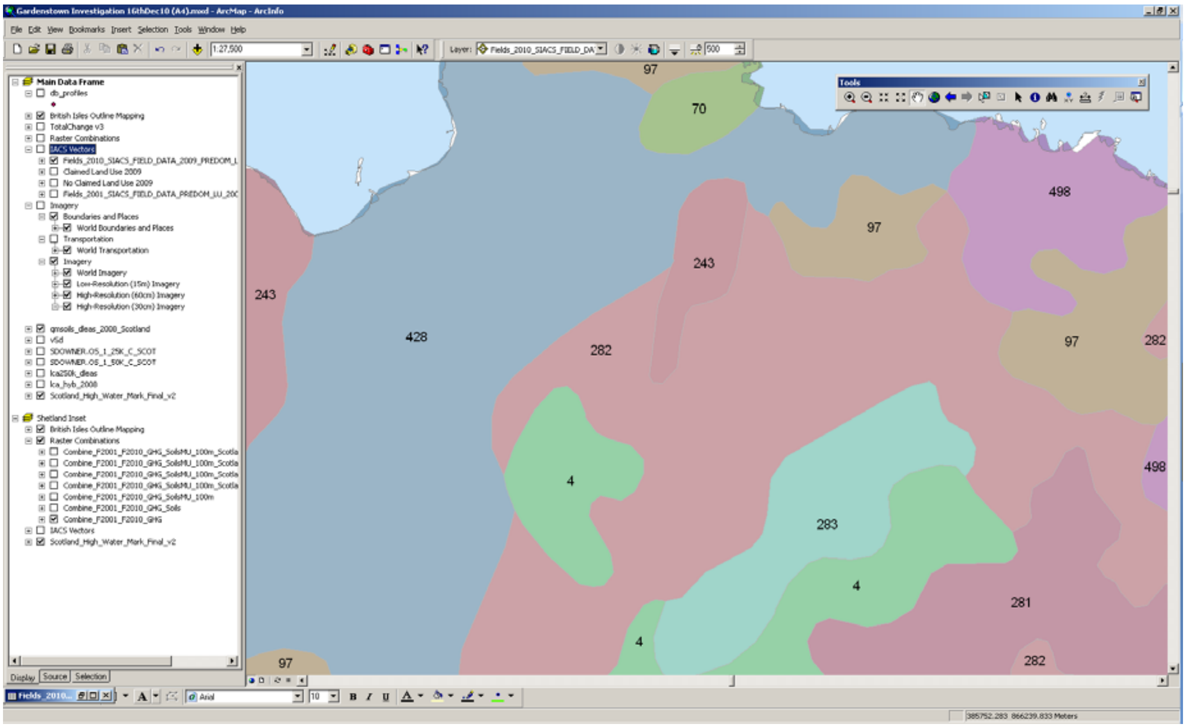

Figure A.2.1. Soil map for a sample area at 1:250,000 resolution

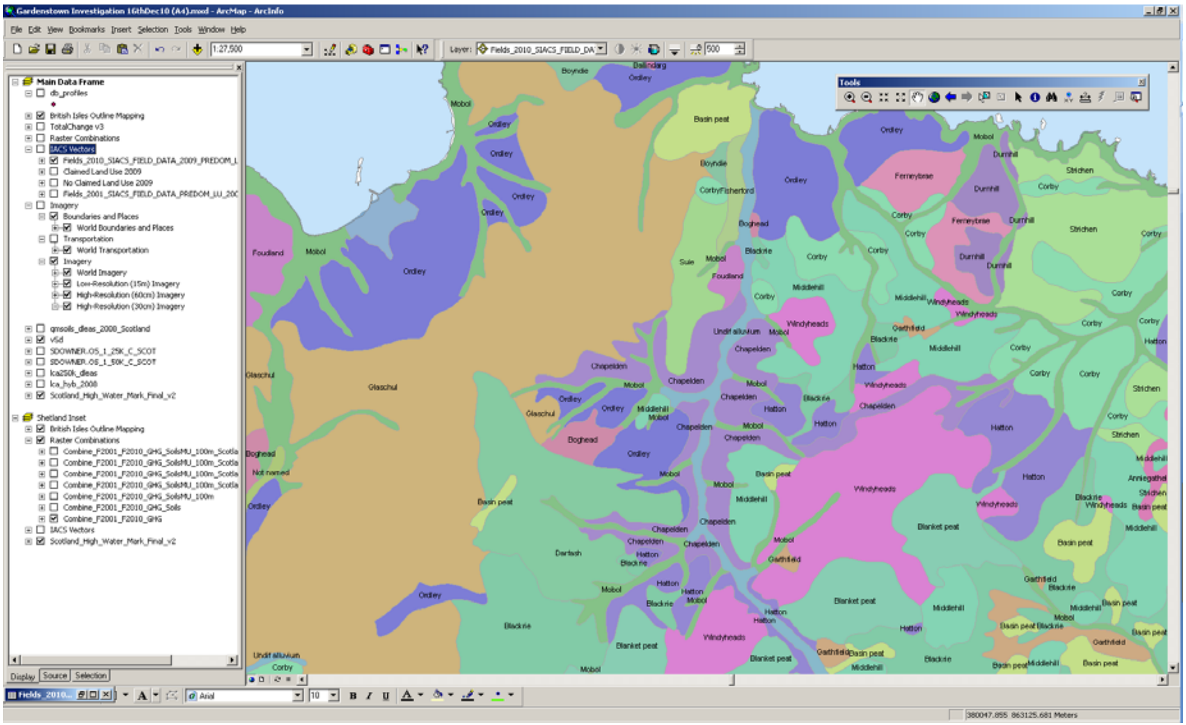

Figure A.2.2. Soil map for a sample area at 1:25,000 resolution

Problems with definition of land use change

The land use data provided by IACS data in 2000 for a sample area is shown in figure A.2.3. The area in the centre of the figure is dominated by grass > 5 years and rough grazing.

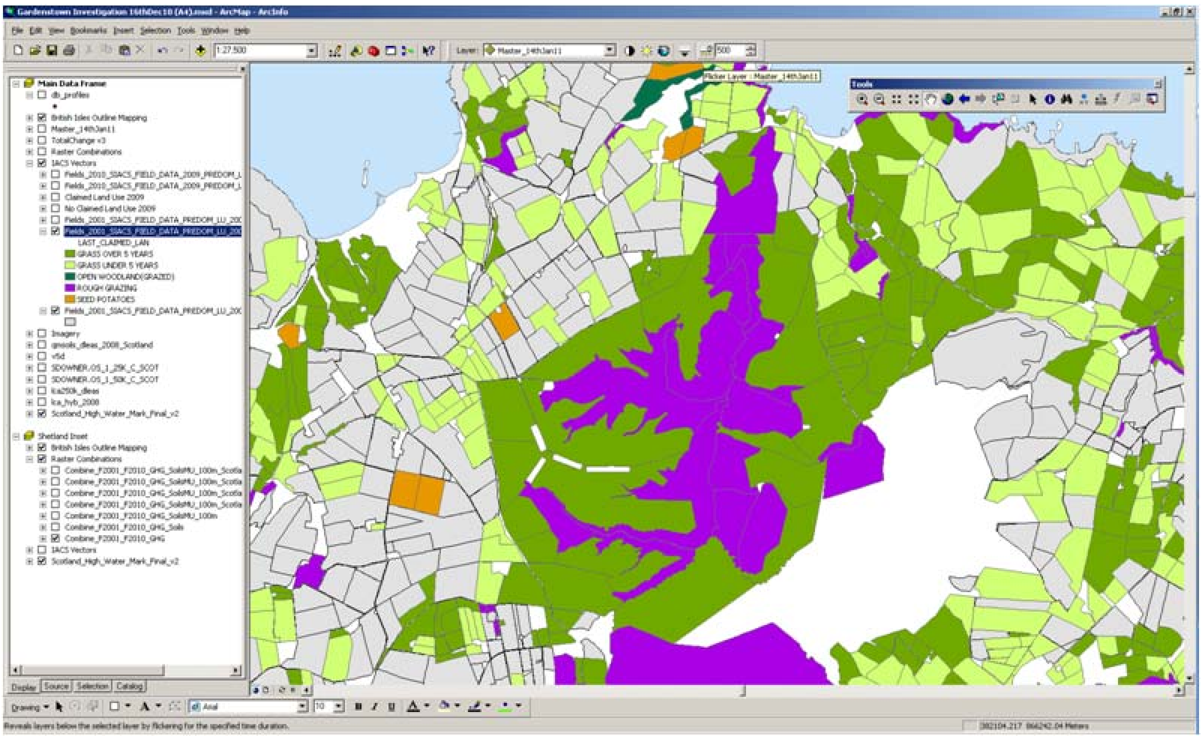

Figure A.2.3. Land use data provided in 2000 by IACS data for a sample area.

The land use data provided by IACS data in 2009 for the same sample area is shown in figure A.2.4. Many changes have occurred since 2000.

(1) Some areas have been converted from grass > 5 years to seed potatoes, so will be classed as land use change grass to arable. Questions arise as to whether the whole area of these large grassland fields has been converted to potatoes. If only a part of the area has been converted, this will result in predominance errors.

(2) Areas of rough grazing have been converted to open woodland, so will be classed as land use change semi-natural to forestry. However, as can be seen in figure A.2.5, this may actually be due to maturation of shrubby rough grazed grassland, and so not actually a distinct land use change. This apparent land use change may be just an artefact of the choice of classification.

(3) In other areas, grass > 5 years has been converted to grass < 5 years, so will be classed as land use change grassland to arable. It is unclear whether this is a real land use change (ie is the area now part of a ploughed and reseeded rotation? Ordinance survey data such as shown in figure A.2.6 could help to interpret such changes. Future work should make use of other data layers, such as Ordinance Survey and Land Cover Scotland 88 to make the land use classification more robust.

(4) Similarly, areas of rough grazing in 2000 are defined as grass > 5. This would be defined as semi-natural to grassland land use change. Ordinance Survey data could be used to determine whether this is a reseed or simply a change in definition.

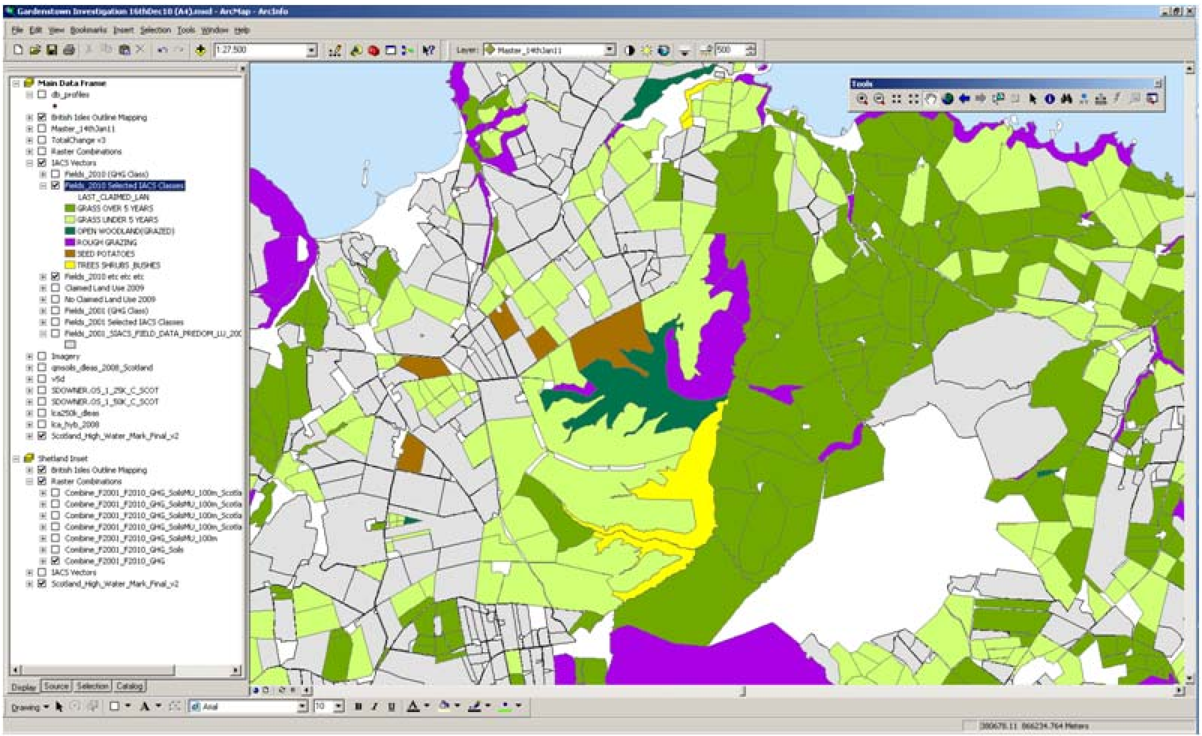

Figure A.2.4. Land use data provided in 2009 by IACS data for a sample area.

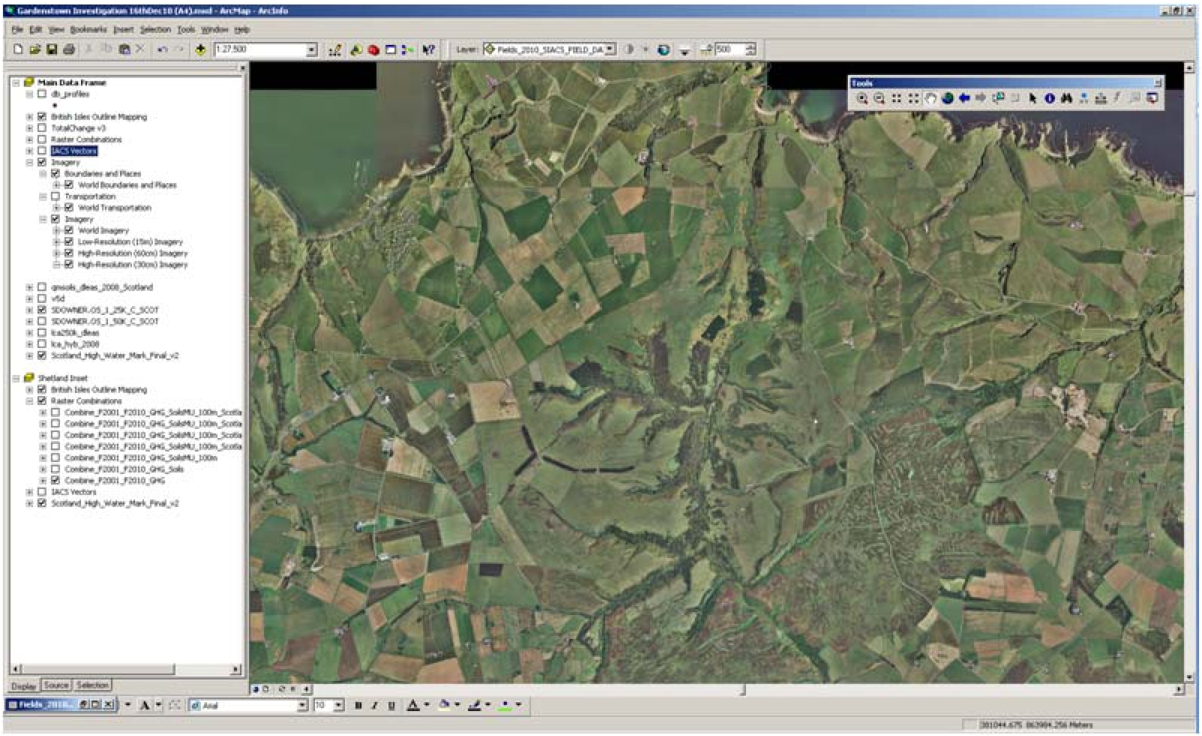

Figure A.2.5. Photograph of sample area showing woodland and grass. The woodland is scattered and open. This area is claimed as rough grazing in 2000, but woodland in 2009, possibly due to maturation of the shrubby area in rough grazing.

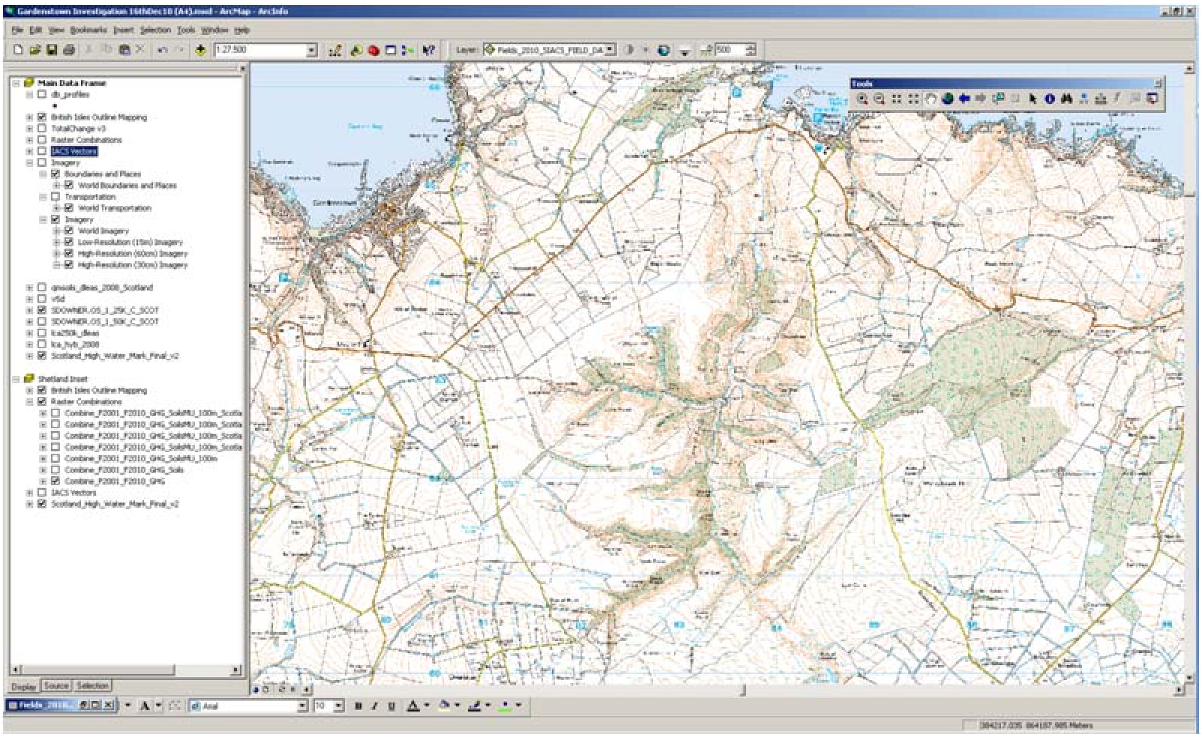

Figure A.2.6. Ordinance Survey map of sample area