SECTION 3

Methodological developments for the UK LUCF GHG Inventory

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Introduction

Two principal sectors are considered in preparing annual carbon dioxide removals and emissions for the UK GHG Inventory.

- Changes in the woody biomass, litter and soils of woodlands and forests are estimated using the C-Flow carbon accounting model driven by Forestry Commission annual planting data. The procedures used are believed to be robust except in their treatment of afforestation of peaty soils and deep peat by conifers. The disturbance of such soils is known to release significant amounts of carbon dioxide that will counterbalance to an unknown extent the new soil organic matter produced from biomass turnover in the new forest. Until recently data on net emissions of carbon dioxide from disturbed peat soils was very limited and as a simple expedient to preparing inventories it was assumed that the losses from the disturbance of the soil would completely counter balance the soil organic matter that accumulated over the rotation of the forest. Recent field measurements (Hargreaves et al. Submitted) are used here to re-assess the contribution of the soil organic matter accumulating in conifer forests to the UK LUCF GHG Inventory.
- Changes in soil carbon due to land use change other than afforestation are estimated using an exponential response model driven by matrices of land use change derived from the Monitoring Landscape change project for the period 1947 to 1980 (MLC 1986) and the ITE/DETR 1990 Countryside Survey (Barr et al. 1993) for the period 1984 to 1990 and extrapolated from 1990 onwards. Soil carbon densities are from a database originally prepared in 1997 (Milne and Brown 1997) but recently partially revised (Milne, Tomlinson and Gauld 2001). A full revision of this database is presently underway and the results should be available by the end of 2003. In addition Countryside Survey 2000 data on land use change for both the periods 1984 to 1990 and from 1990 to 1998 have become available over the last year (Haines-Young 2000). These new data use the concept of Broad Habitats to group changes in land use. The Countryside Survey 1990 presently used for LUCF GHG Inventories uses an earlier land classification so, although the new data covers a longer period, an assessment of the effect of converting to the new land use data is needed. The first opportunity to effectively use the new soil and land use datasets is likely to be the GHG Inventory for 2001 which is to be produced in provisional form for December 2002. The 2000 GHG Inventory was therefore prepared using the existing methods and data but here we discuss some aspects of land use change data highlighted by the Countryside Survey 2000 information.

Soil organic matter in conifer woodlands

Hargreaves et al (Submitted) describes measurements of carbon dioxide over a chronosequence of conifer forests on peatlands starting from an undisturbed moor through to a 26-year old forest. These results are summarised in Figure 1 and show that the undisturbed moor is a small sink for carbon but after ploughing the soil becomes a large source for a few years which reduces sharply then more slowly as the newly planted forest develops. In order to investigate the exchanges with those parts of the system apart form the new forest and its associated new soil organic matter (from biomass turnover) the C-Flow model for conifers was used to estimate the uptake of the forest for three possible yield classes. The equation

Net non-forest C exchange	=	Overall net C exchange	–	Net forest C exchange (gain)
		(measured using eddy covariance)		(estimated using C-Flow model for given volume growth curve (Yield Class))

was then applied to produce the data shown in Figure 2 for the non-forest components. This data suggested that in addition to changes to the original peat and the components of the new forest there was an important sink for about 5 years to temporarily re-established grass before the tree canopy closed canopy. The time series of exchanges in the period from panting up to forest maturity will influence the nest uptake of carbon by the new forest and specifically the balance between the carbon taken up into the new soil organic matter compared to the net loss of carbon from the pre-existing peat and the short term gain by the temporary grass. Each of the components for the non-forest were modelled separately using the equation in Box 1 and plotted in Figure 3. It was assumed that the growing forest was described by the average of the uptake by Yield Class 8 and 10 Sitka spruce forest in the C=Flow model.

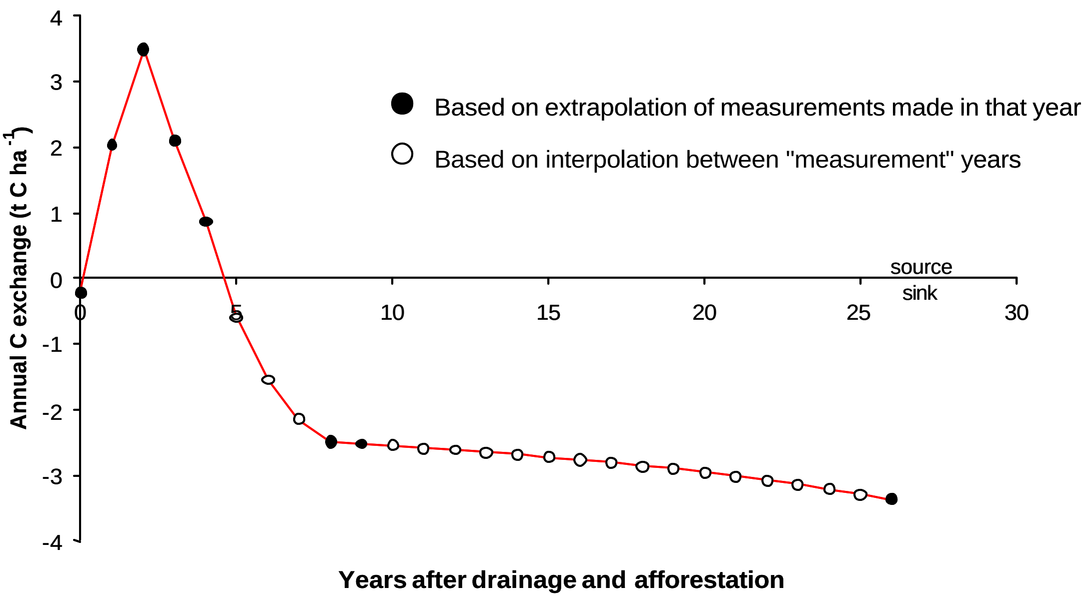


Figure 1. Measured and interpolated net annual carbon exchange for a chronosequence up 26 years of conifer afforestation on peatland.

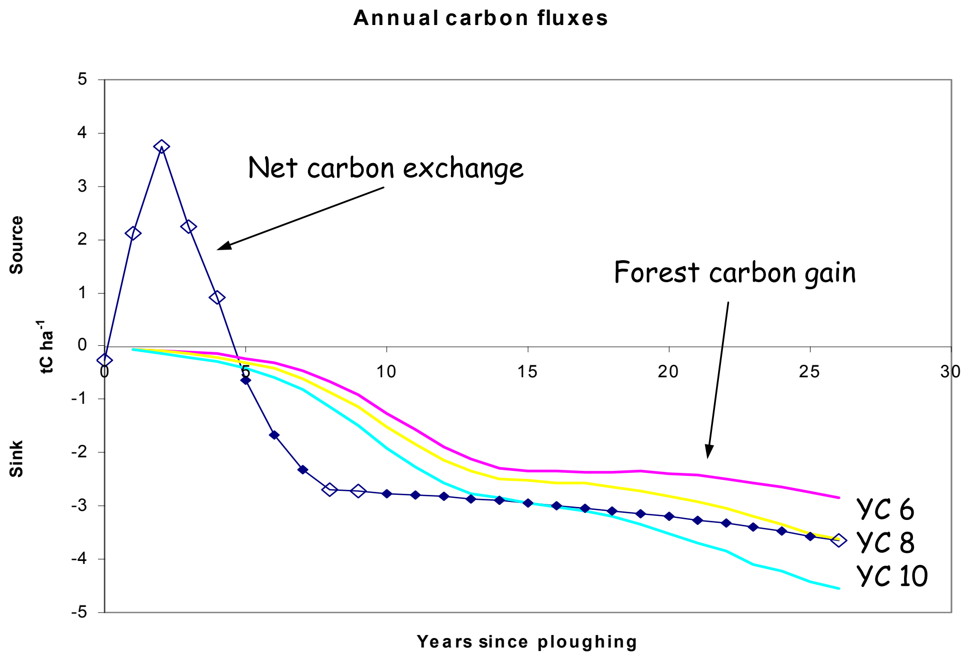


Figure 2. Comparison of measured net exchange at conifer afforestation site with carbon uptake estimated by C-Flow model.

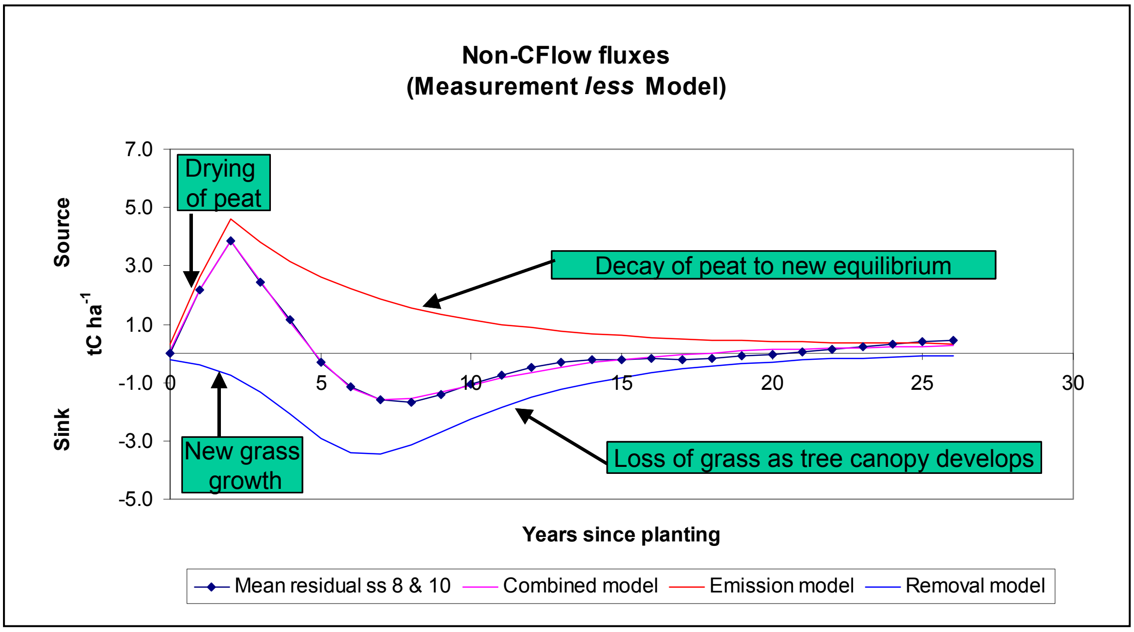
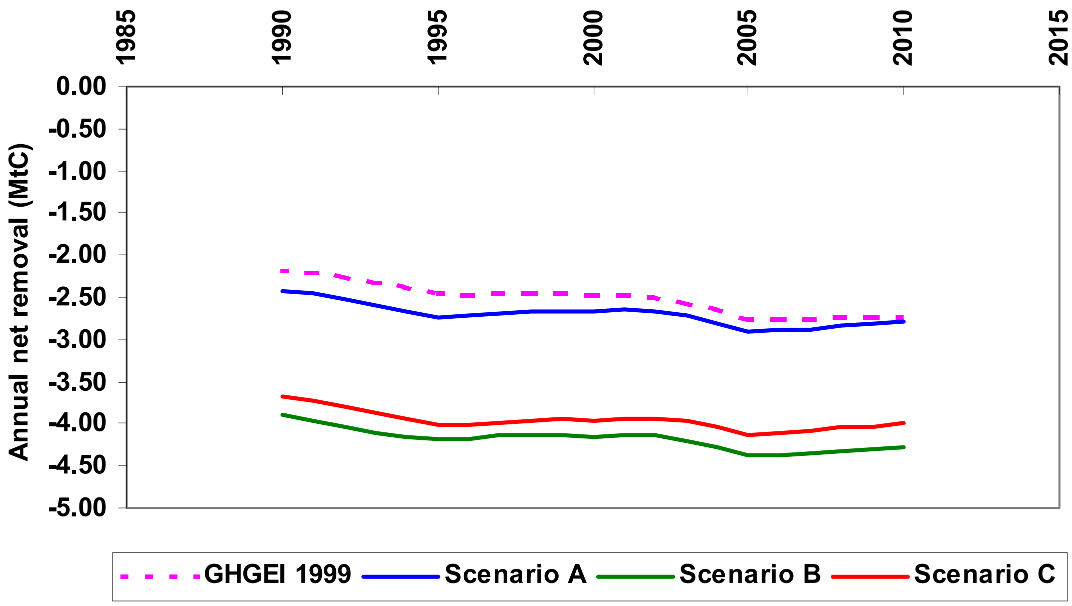


Figure 3. Model fit for non-forest component carbon fluxes after afforestation of peatland.

Source (emission) model	Sink (removal) model
$$E(t)=\frac{E_{\max}e^{-k_1 t}}{1+e^{\frac{(t_e-t)}{\alpha}}}+E_\infty$$	$$R(t)=\frac{R_{\max}e^{-k_2(t-t_{cc})}}{1+e^{\frac{t_g-(t-t_{cc})}{\beta}}}$$
$E(t)$ is source (emission) flux from soil at time t	$R(t)$ is sink (removal) flux to grass at time t
$E_{\max}$ controls maximum source (emission) flux	$R_{\max}$ controls maximum sink (removal) flux
k_1 controls rate of reduction of source (emission) flux	k_2 controls rate that sink (removal) flux dies away
t_e controls timing of maximum source (emission) flux	t_{cc} controls timing of reduction in sink (removal) flux
α controls rate of initial increase in source (emission) flux	t_g controls timing of initial increase in sink (removal) flux due to grass regrowth
E_∞ is final source (emission) flux	β controls rate of initial increase in sink (removal) flux due to grass regrowth

Box 1 Equations for sources and sinks of carbon for non-forest components of process of afforestation of peatland.

Having fitted these equations to the non-forest components these can be combined with the C-Flow model to give a more complete description of carbon exchanges in establishment of conifer forest that is presently adopted in the UK GHG inventory. The question arises however as to the total area of conifer afforestation to which the results shown above might be applicable. In the GHG Inventory no increase in soil organic matter under conifer forests is included and about 200 ha of conifers in the UK are assumed to have been planted on deeper peats which causes an continuing annual loss of 2 tC ha^{-1} a^{-1} or 400 ktC a^{-1} in total. This rate is based on the peak rate of loss from early results of Hargreaves et al (Submitted) and now appears to be significantly too large for any conifer afforestation. It is likely that the losses for different peat and peaty soil locations will be different but a description of such variation is not presently available. In Figure three different options for using the results described here are presented in comparison with the results from the 1999 GHG Inventory and their projection under a “business-as-usual” assumption. Scenario A is that the form of the net losses for non-forest modelled here is applied to all conifer afforestation but the new soil organic matter from the conifer afforestation remains excluded from the calculation. In this case the sink strength is slightly less than that on the existing Inventory assumptions. This is due to the combination of smaller per unit area losses over a forest rotation coupled to a much greater area of conifer afforestation (i.e. all included). Scenario B retains the existing assumption of large losses from deeper peats only but the soil organic matter accumulating under the new forest is included. Scenario C included the smaller peat losses for all conifers and the new soil organic matter. When this latter scenario is applied the net uptake by afforestation in the UK is estimated to be about 1.5 MtC a^{-1} greater than that presently reported to the UNFCCC.



Scenario	Planted peat loss location	Planted peat loss rate	New SOM in conifer forest
GHGEI 1999	Deep peat only	Fixed (0.4 $tCha^{-1}$)	EXCLUDED
A	All conifer planting	Variable	EXCLUDED
B	Deep peat only	Fixed (0.4 $tCha^{-1}$)	INCLUDED
C	All conifer planting	Variable	INCLUDED

Figure 4. The effect of including new results on losses of carbon from peatland after conifer afforestation on the removal of atmospheric carbon to UK forests for three scenarios (See text).

Land use change data

In preparing estimates of changes in soil carbon due to land use change five broad categories have been employed: (Semi-) Natural, Woodland, Farm, Urban and Zero (land with no organic carbon or unclassified). The areas in these categories on different occasions have been calculated from the data of the Monitoring Landscape Change project (MLC) and the Countryside Survey 1990 (see Chapter 1of this report). Countryside Survey 2000 has moved to using Broad Habitat categories for land use/cover not only for the recent survey (1998) but by reclassifying the data stored from 1990 and 1984. The combinations of Broad Habitats appropriate to the five categories for GHG work are shown in Table1.

Table 1 Grouping of Broad Habitats for soil carbon modelling

Broad Habitat		**Carbon class**
Broadleaved, mixed & yew woodland	1	Woods
Coniferous woodland	2	Woods
Boundary and linear features	3	Urban
Arable and horticultural	4	Farm
Improved grassland	5	Farm
Neutral grassland	6	Natural
Calcareous grassland	7	Natural
Acid grassland	8	Natural
Bracken	9	Natural
Dwarf shrub heath	10	Natural
Fen, marsh, and swamp	11	Natural
Bogs	12	Natural
Standing open water & canals	13	Zero
Rivers and streams	14	Zero
Montane habitats	15	Natural
Inland rock	16	Zero
Built up areas and gardens	17	Urban
Sup. littoral rock	18	Zero
Sup. littoral sediment	19	Natural
Littoral rock	20	Zero
Littoral sediment	21	Natural
Sea	22	Zero
Urban		Core urban(Zero)
Unclassified	0	Zero

Land use change matrices for Scotland, England and Wales between 1984 to 1990 and between 1990 to 1998 using the new categorisation have been constructed from data supplied by CEH Merlewood. The areas of the different categories in 1984, 1990 (twice) and 1998 from these matrices is presented in Tables 2 with those from the MLC project and from the Land Use Survey of 1930 (Stamp 1962). There are two estimates for 1990 as the change matrix for 1984 to 1990 is based on a different set of field sites from the change matrix for 1990 to 1998. Most sites are in common (more than 90%) but there are sites specific to each period. Good agreement now exists for the two estimates of land use in 1990 from the Countryside Surveys. It can however been seen that different land classifications usually result in disagreement . The LUS and MLC data do not allow independent estimates of the “Zero” category for example. Further apparent discrepancies between the MLC and CS data are also indicated in the pattern of change recorded over the period. Figure 1 shows these time series and in can been seen for each country that the MLC data for 1980 does not fall on a smooth curve between 1930 to 1947 to 1984. This indicates the uncertainty in such estimates which can also be seen to a certain extent in the Cs data for Wales. In the Figure the time series are also plotted omitting the MLC data to emphasise this issue. If we were only interested in time series of land areas rather than land use change matrices then perhaps the MLC data would be of some value. However when thee land use change matrices for the three periods (MLC 1947 to 1980, CS 1984 to 1990 CS 1990 to 1998) are compared more significant anomalies appear (Fig 2). In Figure 2 the annual change in each 3 periods is plotted for each country. These annual data are calculated by dividing the total change over a period by the length of the period. (The assumption that there is a constant fractional change in land use for any transition produces different values but the conclusion on the MLC data are similar) It then become apparent that the annual rate of change in the significant transitions is much greater from the CS data compared to the MLC. The MLC data is over a longer period which could produce smaller average changes compared to a short period if land is rotated between categories rather than switching permanently from one category to another. The main differences between the data sets however are the land categorisations and the methods (CS field survey, MLC air photo interpretation). The CS data has now been worked on for many years, there are continuing quality control investigations and the Countryside Survey is likely to be repeated in future as part of national land use monitoring it is proposed that new approaches be developed to prepare estimates of change in soil carbon for the LUCF sector of the UK GHG Inventory based only on the CS land use changes matrices with perhaps some initialisation of land use from the 1930 survey.

References

Barr, CJ, Bunce, RGH, Clarke, RT, Fuller, RM., Furse, MT, Gillespie, MK., Groom, GB, Hallam, C.J, Hornung, M, Howard, DC, Ness, MJ, (1993) Countryside Survey 1990, Main Report. London, Department of the Environment.

Hargreaves, K., Milne, R. and Cannell, M.G.R. (Submitted) Carbon balance of afforested peatland in Scotland Submitted to *Forestry.*

Haines-Young, R.H. (2000). Accounting for nature: assessing habitats in the UK countryside. DETR, London

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

Milne, R., Tomlinson, R. W. & Gauld, J (2001). The Land Use Change and Forestry Sector in the 1999 UK Greenhouse Gas Inventory. In: UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities. Annual report for DETR Contract EPG1/1/160 (Ed. by R. Milne) pp 11 – 59.

MLC (1986) *Monitoring Landscape Change* Vols. 1, 1A & 10. Report prepared by Hunting Surveys & Consultants Ltd for Department of the Environment and the Countryside Commission.

Stamp, LD (1962) *The Land of Britain: Its Use and Misuse.* London, Longman

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Scotland km^2	**LUS 1930**	**MLC 1947**	**MLC 1980**	**CS2000 1984**	**CS2000 1990**	**CS2000 1990**	**CS2000 1998**
Farm	1,861,215	2,037,860	2,100,125	2,064,781	1,990,103	1,990,330	1,986,161
Natural	5,265,673	5,209,630	4,667,711	4,791,252	4,798,075	4,798,742	4,738,627
Urban	146,906	260,313	297,076	291,715	297,191	297,155	305,068
Woods	443,187	447,753	890,644	1,091,650	1,151,065	1,151,164	1,200,846
Zero	-	-	-	531,393	534,357	534,383	541,072
Total	7,716,981	7,955,556	7,955,556	8,770,791	8,770,791	8,771,774	8,771,774

England km^2	**LUS 1930**	**MLC 1947**	**MLC 1980**	**CS2000 1984**	**CS2000 1990**	**CS2000 1990**	**CS2000 1998**
Farm	9,542,340	9,242,777	9,013,401	8,593,420	8,303,082	8,303,736	8,255,087
Natural	1,543,000	1,639,511	1,307,178	1,819,009	1,930,469	1,930,482	1,911,020
Urban	1,034,858	823,665	1,301,965	1,357,598	1,446,548	1,446,741	1,491,911
Woods	843,800	865,370	948,779	1,305,679	1,383,875	1,383,103	1,414,399
Zero	-	-	-	400,320	412,052	412,079	403,724
Total	12,963,998	12,571,323	12,571,323	13,476,026	13,476,026	13,476,141	13,476,141

Wales km^2	**LUS 1930**	**MLC 1947**	**MLC 1980**	**CS2000 1984**	**CS2000 1990**	**CS2000 1990**	**CS2000 1998**
Farm	1,094,187	1,061,571	1,148,150	1,098,297	1,009,852	1,009,923	1,009,852
Natural	771,520	701,347	521,131	612,881	673,049	673,132	673,049
Urban	77,298	71,422	121,459	188,341	206,246	206,295	206,246
Woods	120,439	160,077	203,677	221,536	229,502	229,502	229,502
Zero	-	-	-	64,243	66,650	66,644	66,650
Total	2,063,444	1,994,417	1,994,417	2,185,298	2,185,298	2,185,495	2,185,298

Table 2. Land use since 1930 from various sources.

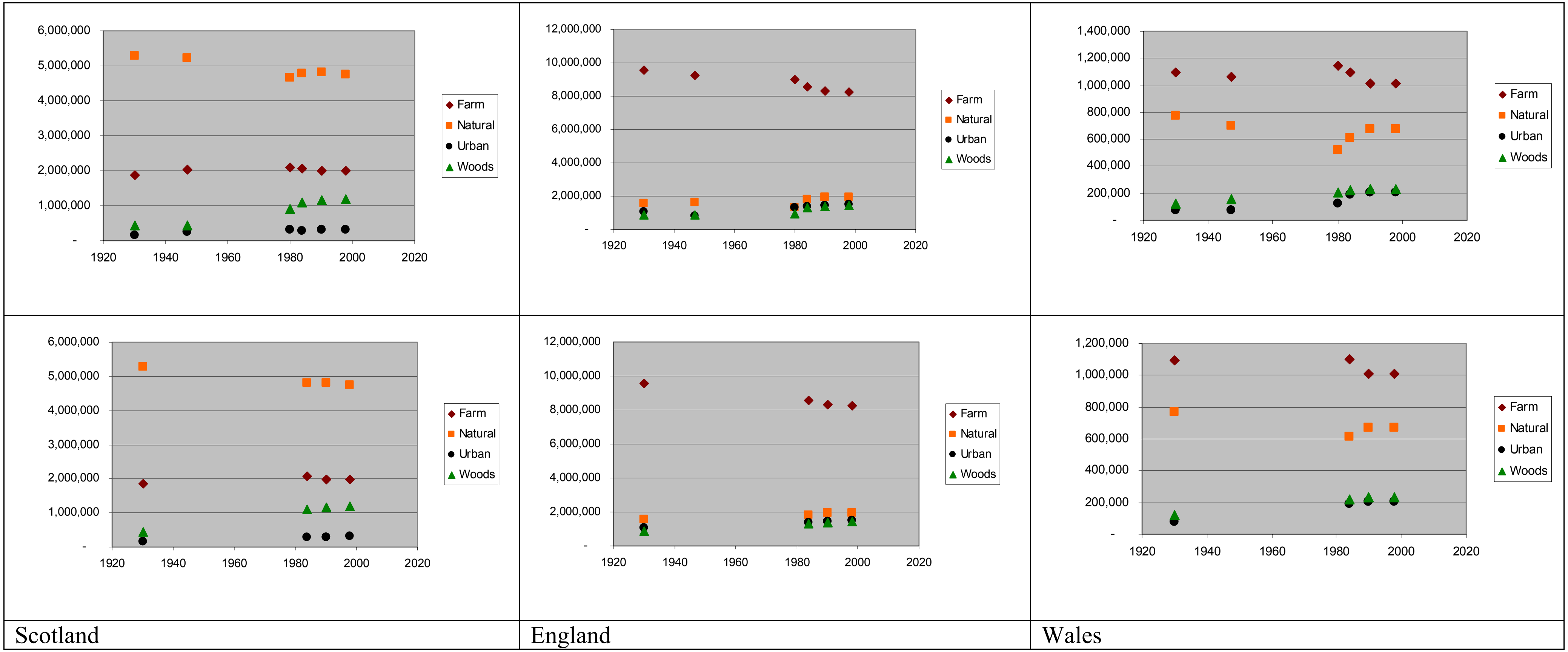
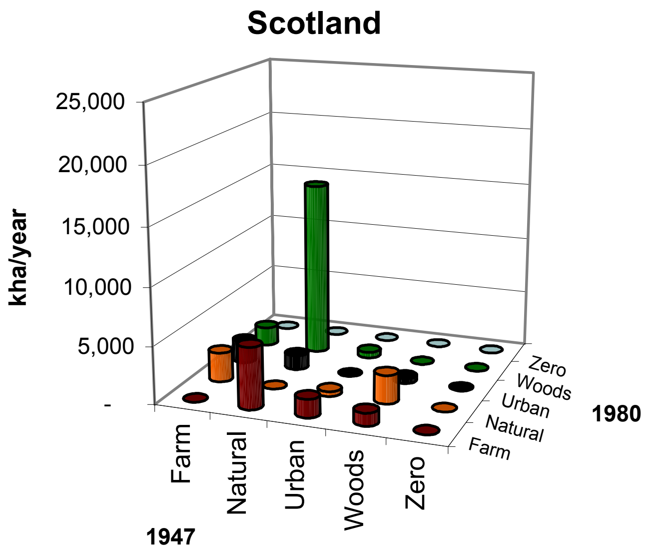
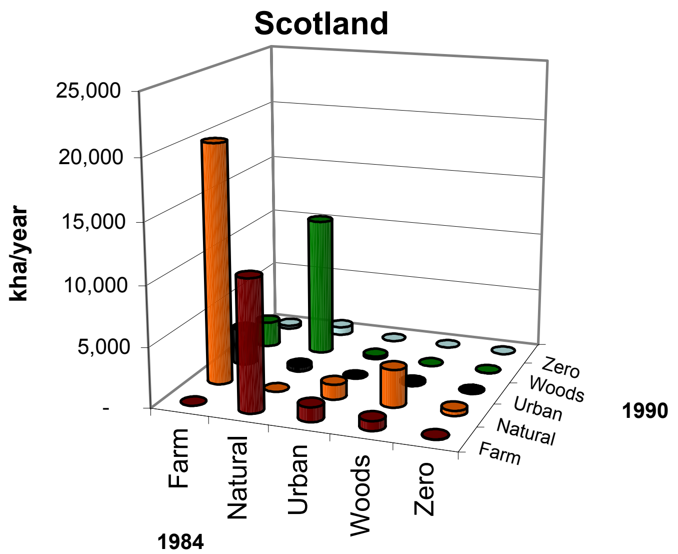


Figure 1 Time series of land use for the devolved regions of Great Britain. Upper row including MLC data for 1947 and 1980, lower row with only LUS data for 1930 and CS data for 1984, 1990 and 1998.





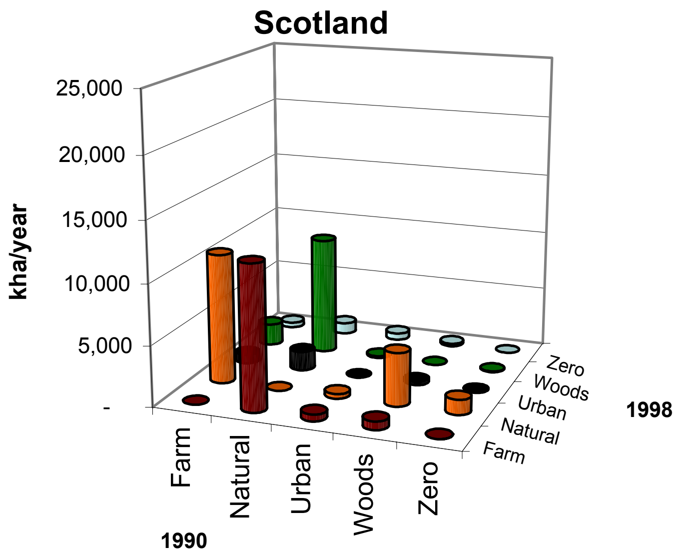


Figure 2a Land use change matrices for Scotland, 1947-80, 1984-90, 1990-98

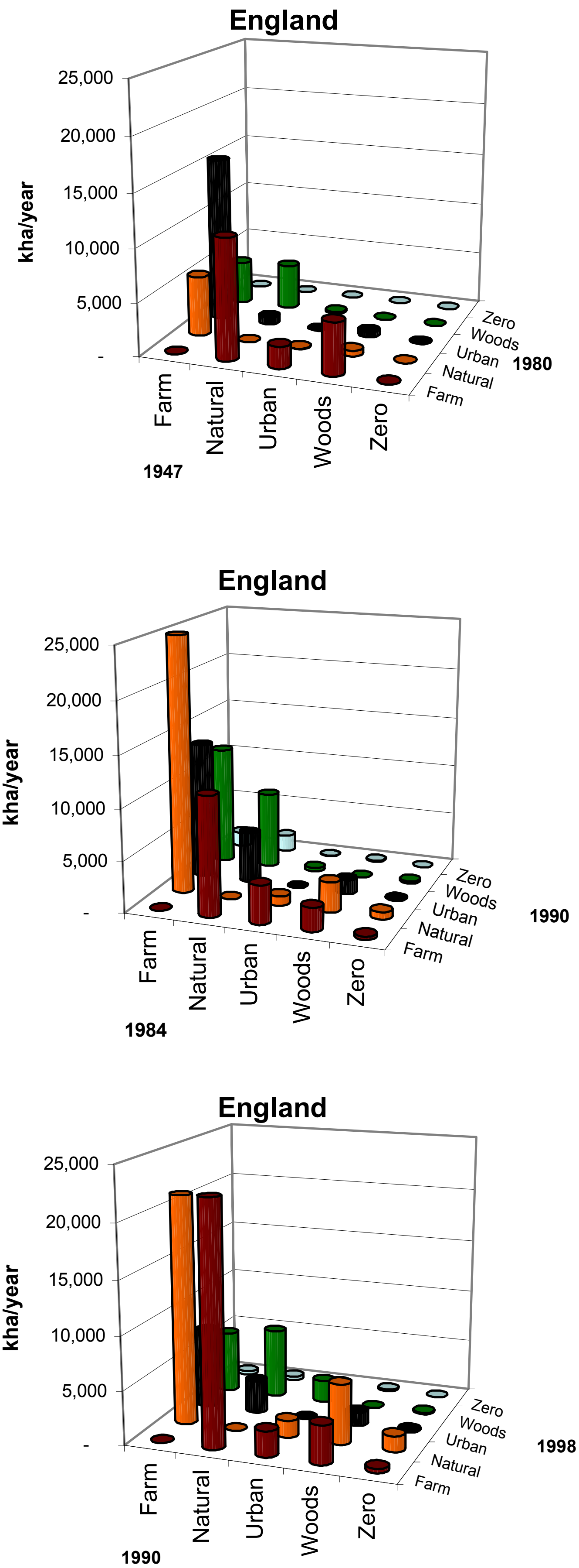
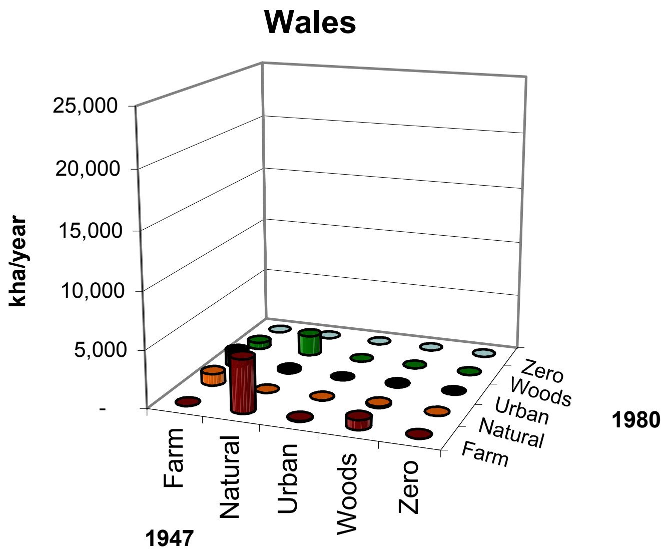
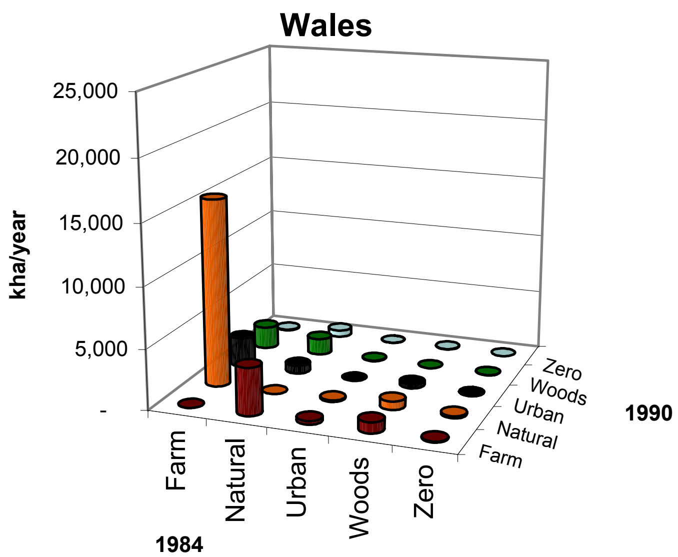


Figure 2b Land use change matrices for England, 1947-80, 1984-90, 1990-98





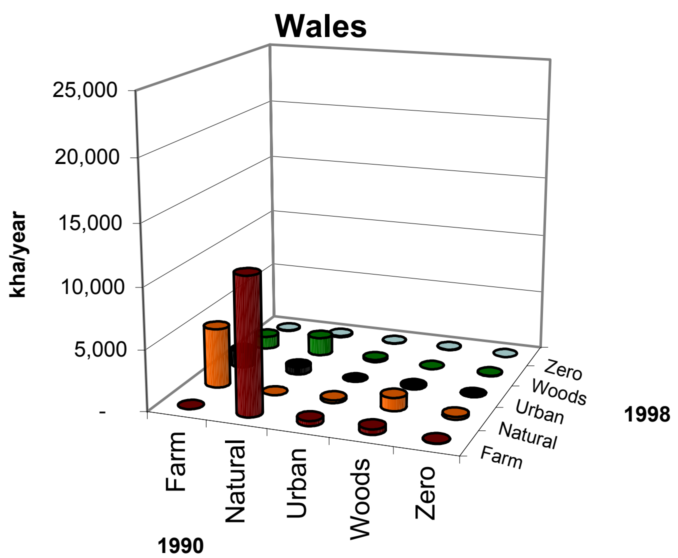


Figure 2c Land use change matrices for Wales, 1947-80, 1984-90, 1990-98