Uncertainties, IPCC Default Methods & New Flux Categories for Carbon in the UK Inventory.

R. Milne, T.A.W. Brown, & T.D. Murray

Institute of Terrestrial Ecology, Bush Estate, Penicuik
Midlothian EH 26 9JF

Summary

- C-FLOW 98 software developed for updating and estimation of uncertainties for carbon uptake to Forestry
- Uncertainty in fluxes of carbon to forest biomass in range +/- 30 -40 % and 50 to 70 % for forest products based on C-FLOW 98 estimates.
- Effect of non-linearities in model on estimated fluxes shown to produce non Gaussian distribution for some parameters.
- The flux of carbon to forests planted or projected up to 2012 are estimated to be such that 1.26 tC ha^{-1} a^{-1} will be taken up between 2008 and 2012 (Kyoto protocol allowance)
- Carbon uptake by expanding area of short rotation coppice at 10000 ha a^{-1} estimated to be 1.62 Mt between 1997 and 2010.
- Four methods for estimating carbon stored in timber products as well as forest biomass are compared.
- Net increase in stored carbon in forest biomass and wood products in 1990 is shown to range from 1.92 to 5.38 Mt a^{-1}.
- C-FLOW 98 method provides most detail on fluxes to forest biomass but is weak on treatment of wood products.
- The draft IPCC method provides most detail for wood products but is very poor for fluxes to forest biomass.

Introduction

In this first year of the present phase of the work on carbon fluxes for UK Greenhouse Gas Inventories relating to the IPCC Land Use Change and Forestry Categories the main objective was to consider uncertainties in the methods presently used initially for Forestry and subsequently for Land Use Change. The need for a more transparent mechanism for updating estimates was also recognised. In relation to Land Use Change it was seen that a model which could be used for updating by using annually published statistics would be useful. Events, particularly conclusions from the Kyoto conference, have however suggested a shift in emphasis. The Kyoto Protocol places particular emphasis on carbon fluxes associated with Afforestation, Reforestation and Deforestation, the first of these being of particular relevance to the UK. The Protocol in addition requires only the fluxes during 2008 to 2012 due to forestry activities since 1990 to be included for negotiation purposes. DETR also consider that new issues to be included in the run up to full implementation of the Kyoto Protocol will require soil carbon to be treated separately for forestry, that uncertainties will continue to be considerable importance and that methods to include carbon stored in forest products will be developed and implemented. Therefore the work reorted here concentrates on Forestry and developments in Land Use Change methods will continue later when results from the projects on the effect of sub^{-1}km2 variation in cover and that on urban soil carbon are available.

Forestry

Updating and estimation of uncertainties

C-FLOW 98 software

A new software package has been developed for use in updating estimates of the carbon flux due to planting of new forests (Afforestation) and providing uncertainties for those estimates. This package (C-FLOW 98) has been written in Borland Delphi (an implementation of Pascal) for use under Microsoft Windows 95. The carbon model used is based on that developed by Dewar & Cannell (1992).

The main features of the package are:

- Easy to use Windows environment
- Holds all data on new planting in UK from 1920 to 1996
- Screen for entry and storage of new planting data for years 1997 onwards from Forestry Commission Annual Report (GB) and Forest Service Annual Report on DANI (NI)
- Screen for entry of scenario projections of planting up to 2020.
- Model parameters can be adjusted
- Uncertainties estimated by use of Monte Carlo method to vary model parameter values.
- Changes in stocks (fluxes) of tree, products and soils displayed separately in a choice of groupings
- Planting of coppice can be included
- Feature to calculate Kyoto style fluxes.

Some example 'screen-shots' are presented in an Appendix 1. The package is available for testing, or use, by those outside ITE Bush but is under continuous development. It has proved effective in exploring many questions related to the Forestry carbon sink and some example results are presented below.

Estimation of Uncertainties (NETCEN)

C-FLOW 98 was used to provide uncertainty ranges for the Forestry categories of the UK Greenhouse Inventory as part of a study looking at possible variation in all of the Inventory Categories. The fluxes and estimated uncertainties supplied to NETCEN are presented in Table 1. These were based on 1000 iterations of the Monte Carlo procedure which varied the model parameters over the ranges shown Tables 2a & 2b which are the default choices for forests consisting of Yield Class 12 Sitka spruce and Yield Class 6 Beech. Most parameters have an uncertainty range of +/- 50% of their most likely value but some are assumed to be known more accurately. Soil carbon was included with forest biomass carbon in these calculations. . The uncertainty rage was assumed to be uniform about the point estimate with no parameter uncertainty. There is however some evidence that the combined variation in parameter values cause a small bias in the mean of the interaction compared to the point estimate. This likely to be due to non-linearities in the model and is discussed further below. Uncertainty in the carbon sink flux for forest biomass (2.57 MtC a^{-1} in 1996) is about +/-30%

but the uncertainty in the increase in the carbon in wood products is +/- 70% on a point estimate of 0.33 Mt a^{-1} in the same year. Also shown are point estimates and uncertainty ranges for Land Use Change Categories.

Treatment of uncertainties in Forestry flux estimates by other countries

For the NETCEN work the approach of other countries to uncertainties in Forestry & Land Use change Inventories was also explored by consultation of published Climate Change Communications which were found to have relevant comment.

Germany: Accepts considerable uncertainty in their emissions data. The main reason is their lack of data on certain emissions-relevant activities - which activities are not stipulated. CO2 emissions are calculated using a sectoral method (Technological Approach) and when compared with the IPCC Reference Approach the results show discrepancies of -.02% to 0.4%.

Netherlands: Take the approach that their estimate of uncertainty on energy produced CO2 to be about 2% and, since non-energy CO2 is only a minor share of the total, even large uncertainties will make little difference to the overall accuracy of total estimates.

Sweden: Regards its non-energy CO2 estimates as having medium reliability and seems to regard them as being mainly a forest sink. Uncertainty has been calculated for energy CO2, mainly from fuel consumption statistics but nothing seems to have been calculated for non-energy CO2.

Canada: Recognises that uncertainty can arise from (a) interpretational differences (source/sink definitions, assumptions, units etc.) (b) errors in socio-economic activity data used to develop emission estimates. (c) inappropriate application of emission factors and (d) actual empirical uncertainty of measured emission data and the basic processes leading to emissions.

Use of the mean and standard deviation of the normal distribution of sectoral expert estimates for each sector and then for each case permitted the addition of sectoral emissions to develop the overall uncertainty. Overall uncertainties for CO2 (4%), methane (30%) and nitrous oxide (40%) were developed using a stochastic model. Individual sector uncertainties can be greater but even so, overall CO2 uncertainties are considered extremely low.

USA: Generally takes no notice of CO2 emissions from the non-energy sector except for a small mention of forest carbon sequestration. Tree carbon estimates are derived from two independent measurements of forest inventories and growth and have standard errors of +/-3%. These estimates do not include forest floor sequestration where the uncertainty is estimated at +/-15%. After 1992, estimates are projected from 1992 data.

Australia: Reports that they have devoted considerable effort to reducing uncertainty, particularly in the area of contribution of land clearing emissions, by improving their understanding of the biosphere but there still remains a high level of uncertainty in these figures and consequently Australia provides estimates for land clearing emissions separately from total greenhouse gas emissions. The overall effect has been to reduce annual emission figures. Australia's estimates for uncertainty are currently +/-30% for rate of change in area cleared and +/-40% for change in carbon per unit area (previously both stood at +/-50%).

More work is being done to further reduce uncertainty in area and rate of land clearing and in biomass and soil carbon estimates.

Satellite information has been primarily responsible for the reduction of uncertainty in land clearing rates. Woody weed invasion is now being taken into account but soil carbon emissions resulting from disturbance are still the most uncertain aspect of clearance estimates.

Australia uses the IPCC low/medium/high level of confidence methodology where, for agriculture, forestry and land use High <20%, Medium =20-80% and Low >80% uncertainty. This means that emissions from land use change and forestry fall into the Low category with an uncertainty of >80%.

Uncertainty in the forestry sector is given a conservative approach. Appropriate available data was used for area of commercial plantations and tree growth rate (where there is reasonable confidence in the figures). There was less confidence in the figures for managed native forests so conservative figures were used and low estimates were used for revegetation where confidence in the figures is low. As a result, Australia's forests are liable to be a greater sink for CO2 than the figures suggest.

Distribution of estimates of forestry carbon fluxes resulting from Monte Carlo variation of parameter values.

Uncertainty in estimates of the carbon flux in 1996 due to increase in forest biomass (including litter but excluding soil carbon) was investigated by plotting histograms of estimated values for series of 500 iterations of C-FLOW 98 where each series was run with different ranges set for chosen model parameters. All runs were based on the assumption that conifers in the UK can be represented by Sitka spruce Yield Class 12 and beech Yield class 6 characteristics. Historical planting was used up to 1996. The results for the default parameter set are shown in Figures 1a & b and Table 3.

Table 3: Point estimate (i.e. with fixed parameters) compared with mean from 500 random selections of parameter combinations and standard deviation of variation for carbon pools in UK forests using default parameter ranges.

	Point estimate MtC a^{-1}	**Mean estimate MtC a^{-1}**	**Standard deviation MtC a-1**	**Standard deviation %**
Forest	2.380	2.290	0.810	35.000
Products	0.310	0.370	0.250	68.000
Soil	0.170	0.170	0.030	19.000

The standard deviation of the estimates of flux to trees is 35% of the mean and for products 68% of the mean. The variation in parameters however gives mean values for fluxes different from the point estimates with fixed parameters. The distribution of estimates shows a complicated shape reflecting the non-linear interaction of the parameter values. The effect of variation in the harvest fraction for foliage and woody roots i.e. the unharvested biomass left after felling, with fixed values for all other parameters is shown in Figure 2 and Table 4.

Figure 1a Distribution of estimates using Monte Carlo variation of parameters of C-Flow model using default ranges.

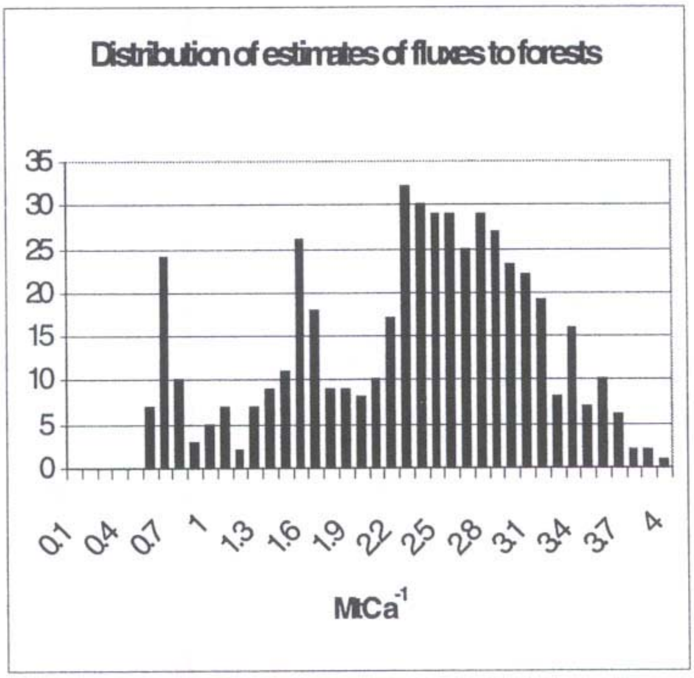


Figure 1b.

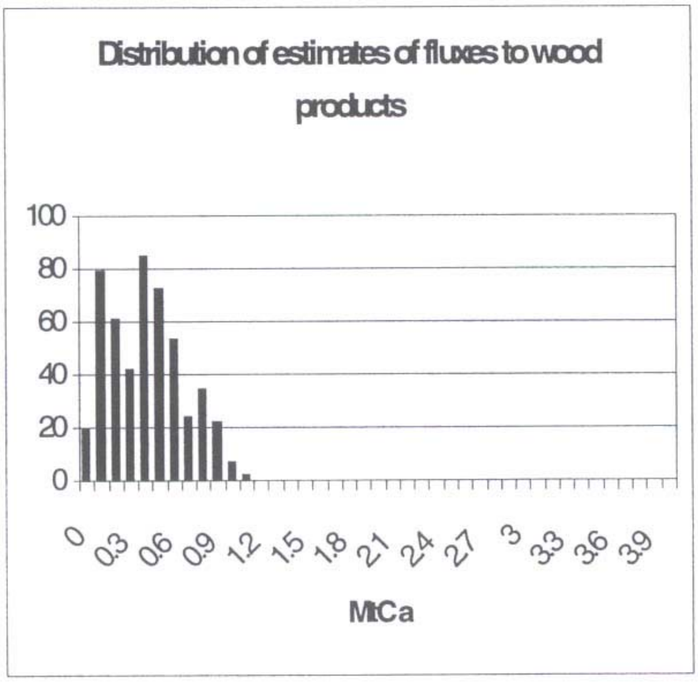


Table 1: Data supplied to NETCEN on uncertainties in estimates of fluxes to various categories (pre 1996 Revision definitions of Tables) in IPCC Greenhouse Gas Inventory of Forestry & Land Use Change for UK

IPCC Table (pre 1996)	Title	UK Process	Net carbon change(Gg) (- loss from atmosphere, + emission to atmosphere)				Error +/-%				Error method	Use with @RISK
			1990	1995	1996	2010	1990	1995	1996	2010		
5A Sheet 1	Forestry	Forest biomass change	-2216	-2578	-2570	-2552	30	30	30	40	Variation in model parameters	Assume Standard Deviation of Gaussian Distribution
5A Sheet 2	Forestry	Timber products change	-425	-309	-327	-721	50	70	70	50	Variation in model parameters	Assume Standard Deviation of Gaussian Distribution
5B Sheet 3	Forest/Grassland conversion	Above ground biomass decay (grassland)	-300	-300	-300	-300	50	50	50	50	"Expert judgement"	Assume Range for Uniform Distribution
5B Sheet 4	Forest/grassland conversion	Soil carbon release (grassland)	7544	7147	7061	6078	60	70	70	90	Variation in model parameters	Assume Range for Uniform Distribution
5C Sheet 1	Abandonment	Set aside	-382	-2148	-2095	-1476	50	50	50	50	Variation in model parameters	Assume Range for Uniform Distribution
5D	Other	Upland peat drainage	400	400	400	400	50	50	50	50	"Expert judgement"	Assume Range for Uniform Distribution
5D	Other	Lowland wetland drainage	400	400	400	400	50	50	50	50	"Expert judgement"	Assume Range for Uniform Distribution
5D	Other	Peat extraction	200	200	200	200	10	10	10	10	"Expert judgement"	Assume Range for Uniform Distribution

Table 2a: Default parameter values and uncertainty ranges for Sitka spruce Yield Class 12 forests in C-FLOW 98 software.

Variable	Low	Value	High	S.E. (%)
Branch harvest fraction	0.045	0.090	0.135	50
Stem harvest fraction	0.045	0.050	0.055	10
Woody root harvest fraction	0.095	0.190	0.285	50
Rotation length (years)	29.500	59	88.500	50
Wood density (Mg m-3)	0.310	0.360	0.410	14
Asymptotic foliage mass (Mg C ha^{-1})	4.320	5.400	6.480	20
Asymptotic fine root mass (Mg C ha^{-1})	2.160	2.700	3.240	20
Product life (years)	29.500	59.000	88.500	50
Thinning life (years)	2.500	5.000	7.500	50
Asymptotic foliage litter rate (y^{-1})	0.550	1.100	1.650	50
Asymptotic fine root litter rate (y^{-1})	1.350	2.700	4.050	50
Foliage decomposition rate (y^{-1})	0.500	1.000	1.500	50
Wood decomposition rate (y^{-1})	0.030	0.060	0.090	50
Fine root decomposition rate (y^{-1})	0.750	1.500	2.250	50
SOM decomposition rate (y^{-1})	0.015	0.030	0.045	50
Fraction transfer litter to soil	0.400	0.500	0.600	20

Table 2b As above for beech Yield Class 6 forests.

Variable	Low	Value	High	S.E. (%)
Branch harvest fraction	0.090	0.090	0.270	50
Stem harvest fraction	0.045	0.050	0.055	10
Woody root harvest fraction	0.080	0.160	0.240	50
Rotation length (years)	46.000	92	138	50
Wood density (Mg m-3)	0.473	0.550	0.627	14
Asymptotic foliage mass (Mg C ha^{-1})	1.440	1.800	2.160	20
Asymptotic fine root mass (Mg C ha^{-1})	2.160	2.700	3.240	20
Product life (years)	46.000	92	138	50
Thinning life (years)	2.500	5.000	7.500	50
Asymptotic foliage litter rate (y^{-1})	1.000	2.000	3.000	50
Asymptotic fine root litter rate (y^{-1})	1.350	2.700	4.050	50
Foliage decomposition rate (y^{-1})	1.500	3.000	4.500	50
Wood decomposition rate (y^{-1})	0.020	0.040	0.060	50
Fine root decomposition rate (y^{-1})	0.750	1.500	2.250	50
SOM decomposition rate (y^{-1})	0.015	0.030	0.045	50
Fraction transfer litter to soil	0.400	0.500	0.600	20

Figure 2 Distribution of estimates due to varying turnover time of SOM and fine roots harvest fraction of foliage and woody roots.

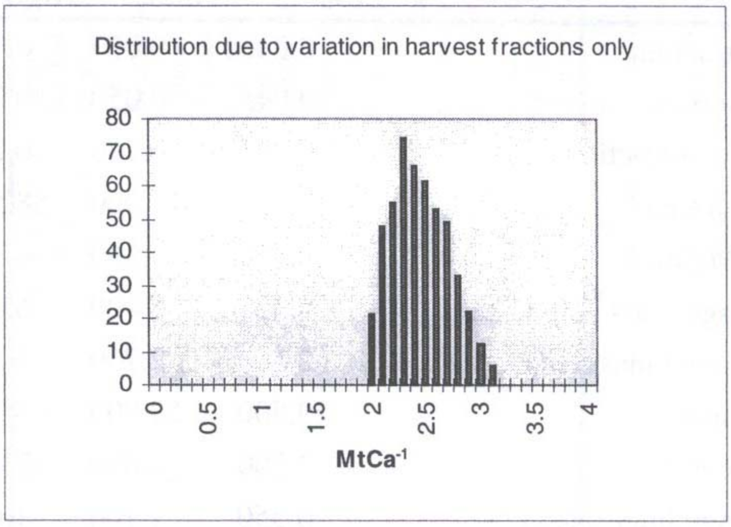


Table 4:Point estimate (i.e. with fixed parameters) compared with mean from 500 random selections of parameter combinations and standard deviation of variation for carbon pools in UK forests using variation in harvest fraction parameter values only.

	Point estimate MtC a^{-1}	**Mean estimate MtC a^{-1}**	**Standard deviation MtC a^{-1}**	**Standard deviation %**
Forest	2.380	2.400	0.260	11%
Products	0.310	0.313	0.001	0%
Soil	0.170	0.167	0.030	2%

Variation in these parameters follows a distribution similar to the Gaussian with a cut-off at lower values. However variation due to different rotation times has a pattern of an unusual shape (Figure 3, summary in Table 5).

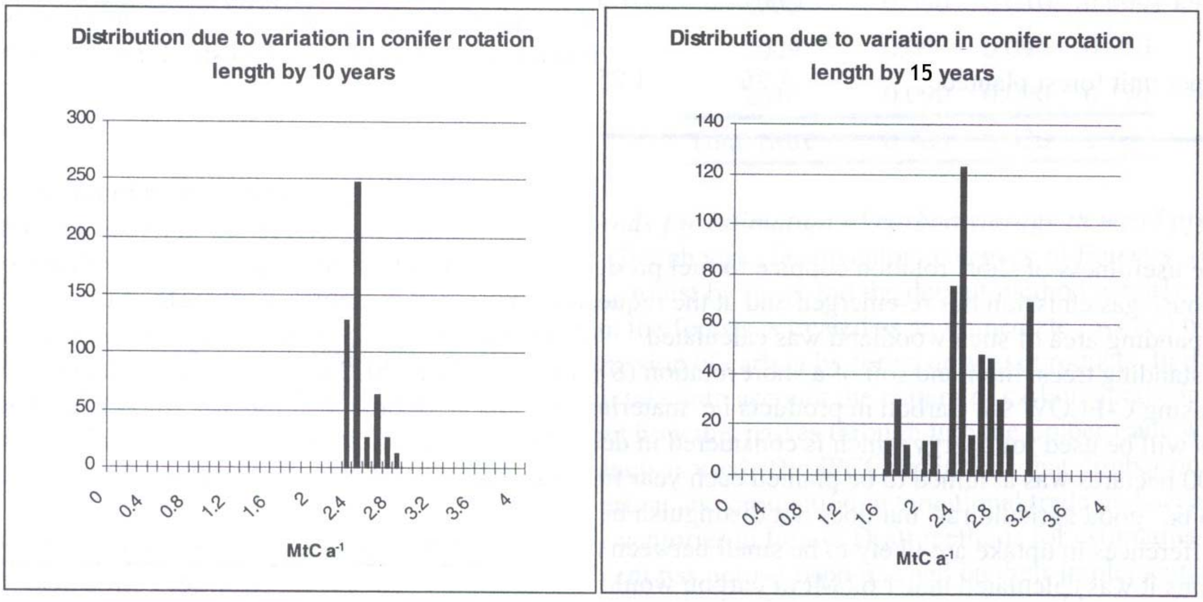
Table 5a - Mean estimates for variation of rotation length by ten years above and below default.

Variation of 10 years in rotation	**Point estimate MtC a^{-1}**	**Mean estimate MtC a^{-1}**	**Standard deviation MtC a^{-1}**	**Standard deviation %**
Forest	2.376	2.376	0.113	5%
Products	0.313	0.345	0.138	40%
Soil	0.167	0.167	0.000	0%

Table 5b - As 5a but for twenty year variation

Variation of 10 years in rotation	**Point estimate MtC a^{-1}**	**Mean estimate MtC a^{-1}**	**Standard deviation MtC a^{-1}**	**Standard deviation %**
Forest	2.376	2.420	0.387	16%
Products	0.313	0.341	0.201	59%
Soil	0.167	0.167	0.000	0%

Figure 3: Distribution of estimates of carbon fluxes to forest biomass with Monte Carlo variation of rotation length



The rotation length of both conifer and broadleaf forests were allowed to vary within the Monte Carlo procedure by 10 years and 15 years either side of the defaults for the 10 years variation a fairly simple distribution is obtained (Fig 3a) but allowing 15 years variation in rotation length cause a group of smaller estimates of flux to forest biomass to be generated. With the availability of the Monte Carlo procedure within C-Flow 98 such non-linear interactions of the parameter values will be investigated to provide better estimates of the likely error in carbon fluxes associated with Forestry for inventories and projection s for the UK.

Kyoto Protocol fluxes

The Kyoto Protocol proposes that changes in stocks of carbon in forests the years 2008 to 2012 due to Afforestation, Deforestation and Reforestation due to activities since 1990 can be taken into account in assessing countries success in meeting the Protocols carbon emission target. C-Flow 98 was used to make a preliminary estimate of the appropriate UK flux. New planting in the UK recorded from 1990 to 1996 was used with a projection of the annual planting rate for each year from 1997 to 2012 equal to that which occurred in 1996 (7.4 kha a^{-1} of conifer and 8.9 kha a^{-1} of broadleaf forest). The results (Table 6) are that if planting continues at the 1996 rate then in the period 2008 to 2012 UK forests planted from 1990 will have taken up an average of 1.26 tC ha^{-1} a^{-1} to forest biomass in those 5 years.

Table 6 Carbon uptake in period 2008 to 2012 by forests planted after 1990

	Conifer	**Broadleaf**	**All forest**
Average annual uptake 2008 to 2012 (MtC a^{-1})	0.25	0.250	0.5
Total new area 1990 to 2012 (kha)	193.7	201.5	395.2
Uptake rate per unit forest planted. (tC ha^{-1} a^{-1})	1.26	1.25	1.26

Short Rotation Coppice

Recently interest in the usefulness of short-rotation coppice to fuel production in the context of reduction in greenhouse gas emission has re-emerged and at the request of MAFF the carbon stored in an expanding area of such woodland was calculated

Carbon storage in the standing trees, litter and soil of a short rotation (8 year) willow coppice stand were estimated using the C-FLOW 98. Carbon in products i.e. material removed from site is not presented as this will be used for energy which is considered in detail elsewhere.

An extra area of 10,000 hectares was assumed to be planted each year from 1997 to 2010. The soil is assumed to be "good agricultural" but does not distinguish between tilled and grassland, although differences in uptake are likely to be small between these soil types.

Under these assumptions it was calculated that 1.62 Mt of Carbon would be taken up between 1997 and 2010 (Table 7)

Estimates of carbon uptake for 1997

The new areas of forest planted between 1996 and 1997 were added to the C-FLOW 98 database and the net uptake of carbon for that period calculated. the new area was similar in each country to that in the previous years and it was estimated that 2.38 $MtCa^{-1}$ were taken up by forest biomass, 0.29 $MtCa^{-1}$ by products and 0.17 $MtCa^{-1}$ by forest (broadleaf) soil.

Table 7: Uptake of carbon by short rotation coppice assuming an extra 10,000 ha planted per year after 1997

Year	**Uptake rate (Mt C year^{-1})**		
	Trees +Litter	**Soil**	**Trees +Litter + Soil**
1997	0.000	0.000	0.000
1998	0.020	0.000	0.020
1999	0.030	0.010	0.030
2000	0.040	0.020	0.050
2001	0.050	0.020	0.080
2002	0.080	0.030	0.110
2003	0.130	0.040	0.170
2004	0.170	0.050	0.220
2005	0.200	0.060	0.250
2006	0.040	0.070	0.100
2007	0.040	0.080	0.120
2008	0.050	0.080	0.130
2009	0.060	0.090	0.150
2010	0.090	0.090	0.190
Total (Mtonnes C)	0.980	0.630	1.620

Comparison of methods for estimation of carbon storage in wood products

At present the IPCC Greenhouse Gas Inventory category of Forestry only considers increases in carbon for standing forest biomass and the default method is fairly simple (IPCC 1996). Wood harvested from the forests is treated as an immediate loss and no account is taken of delayed uptake or emission of carbon by forest or wood products In the UK we have used a carbon flow model to take into account the pattern of carbon uptake in new plantings of forests since 1920 and how this passes through into the timber trade where an exponential decay of timber products id used. The IPCC recognises that timber products contain an important stock of carbon and production, international trade and decay of these products should be added to inventories in future. Draft methods for estimating these flows were produce but agreement has not yet been reached on their implementation.

Here we compare four methods of estimating the gains and losses of carbon due to both forestry operations and the production, trade and use of timber products. The methods are compared for 1990 (all data not yet available for later) and are 1) the C-Flow model used at present, 2) C-Flow with additional consideration of international trade in products, 3) IPCC default method as described in 1996 Revised Guidelines (IPCC 1996) and 4) a simplified implementation of the methods described in the draft IPCC methods for treating carbon in timber products which has not yet been implemented. The results of the comparison are presented in Table 8.

Table 8: comparison of estimates of changes (MtC a^{-1} in 1990) in storage from 4 methods of assessing carbon in forest biomass and wood products.

Type of change	**Component**	**C-FLOW 98**	**IPCC 1996**	**C-FLOW 98 plus products**	**IPCC Draft for products**
New material	Biomass		4.830		4.830
	Trees	1.996		1.996	
	UK Products	0.578		0.578	
	Net product import			5.600	
	net commod in				7.513
Changes in stored products	UK products	-0.154	-2.909	-0.154	
	Litter				-0.772
	Net products import			-4.610	
	allprod				
	pulpexp				0.010
	immedloss				-2.626
	delayed loss				-3.572
Net gain carbon		2.420	1.921	3.410	5.383

C-FLOW

The C-FLOW 98 software was used to estimate the change in the stock of carbon in forest biomass and timber products. This model assumes that changes in forest biomass and products are only due to new forest planted in the UK since 1920 and that an area of forest equivalent to that which existed before that data is considered to be in equilibrium and hence not contributing to carbon uptake. New forests are assumed to pass through continuing rotations, being clearfelled and replanted at an age determined by standard industry yield tables. Timber products from conifer and broadleaf forest are estimated separately and these are assumed to decay following an exponential pattern with a lifetime equal to the respective rotation lengths. The model is described in Dewar & Cannell(199) and Cannell & Dewar (199) and how different assumptions on yield class variation across the country affects flux estimates is described by Milne et al (1998). For inventory purposes all planting is assumed to have the characteristics of Yield Class 12 Sitka spruce for conifers and Yield Class 6 beech for broadleaves. Planting areas are those recorded by Forestry Authority for both state and private forests.

The results for C-FLOW show increases in both the stock of carbon in forest biomass and in timber products with a net uptake of 2.4 MtC a^{-1}. It was also estimated that the net increase in carbon in products was made up of an increase of 0.58 Mt a^{-1} due to new products being added to the pool but with a loss of 0.15 MtC a^{-1} loss from existing products due to decay.

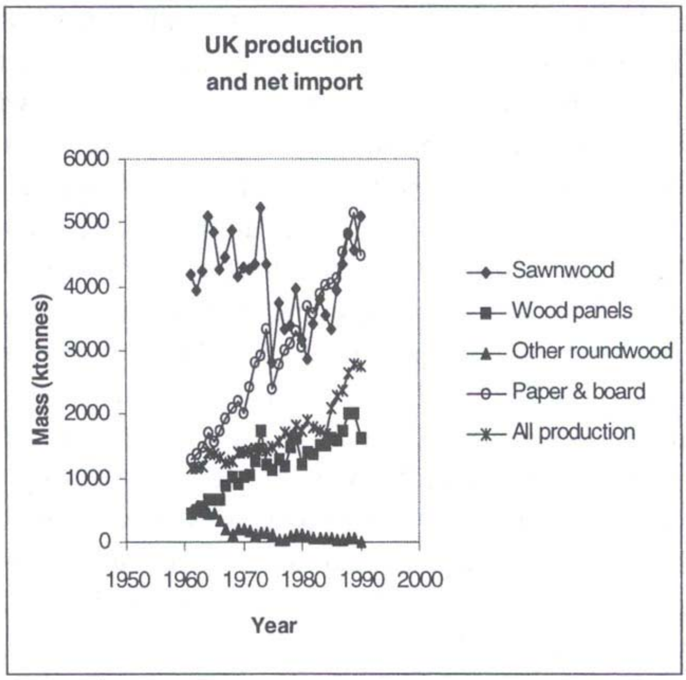
CFLOW plus wood product trade

In order to consider the effect on stocks of carbon in products due to import and export data from the FAO products database which covers the period from 1961 onwards was utilised. Following the draft IPCC method for products (see below) trade is considered in four categories: sawn wood, wood based panels, paper & paperboard and miscellaneous other roundwood. Each of these type was assigned wood densities and product lifetimes based on data in the IPCC draft method (See Table 9).

Table 9: Parameters for different types of wood products used in models of carbon uptake and loss.

	Sawn wood	**Wood panels**	**Paper & board**	**Other roundwood**
Density (t m^{-3})	0.48	0.52	(tonnes)	0.6
Lifetime	100	50	12.5	25
Long-term Fraction	0.8	0.9	0.6	0.7

Figure 4: Comparison of UK timber production with net imported timber



The net trade (import - export) is shown in Figure and it should be noted that this is much greater than the UK production and that the main commodities are imported sawnwood and paper based products.. The mass traded since 1961 in each product was assumed to decay exponentially with the lifetime as shown in Table and the e resulting change of stored carbon in 1990 was found to be an increase of 0.99 Mt a^{-1} resulting from an increase 0f 5.60 Mt a^{-1} in the stock from the products imported in that year but reduced by 4.61 Mt a^{-1} due to decay of products already in use. Taking these figures with those for uptake to forest biomass and UK products as calculated by C-FLOW 98 the net gain in stored carbon was estimated to be 3.41 MtC a$^{`}$, most of this due to imported sawnwood.

IPCC 96 method

The present default method for the carbon inventory for Forestry (IPCC 1996) is based on fairly simple assumptions, namely that carbon uptake by forest can be estimated by the product of total area and a mean uptake rate for these forests and that 'loss' of biomass into products can be estimates from production statistics and is considered to be an immediate loss. The most uncertainty in this approach is due to the difficulty in assigning a suitable mean carbon uptake rate. Default values are suggested in the IPCC Guidelines but there are none that appear directly applicable to UK forests. Here a rate is estimated by averaging the net uptake rate for new forest as calculated by C-FLOW 98 by the total area of new forest in 1990. This results in a value of about 2 tC ha^{-1} a^{-1} which is similar to those quoted for temperate forest in the IPCC Guidelines. The carbon lost from forest biomass in harvested products is calculated from Industrial Roundwood production statistics scaled up to include the non harvested parts of the tree using the IPCC 1996 default wood density and expansion factor. The resulting uptake by forest biomass was 4.83 MtC a^{-1} with 2.91 MtC a^{-1} going to products, a net uptake of 1.92 MtC a^{-1}.

IPCC Draft for wood products

A method of using FAO Trade statistics in timer to estimate changes in the stock of carbon in timber products was developed by the IPCC and although this approach has not yet been implemented it is fully described in the draft documentation. Here we applied this method to the UK but with some simplification ignoring differences in parameters for coniferous and other forests which were considered to be of a relatively minor nature.

The method retains the IPCC 1996 approach of forest biomass uptake but adds considerable more detail to the description of products. A net change in the mass of products is calculated from production and trade statistics. A fraction of this mass is assumed to be lost immediately and the rest goes into long-term storage from where it decays at a uniform rate over a defined lifetime. Products are categorised into Sawnwood, Wood based panels, Paper & paperboard and miscellaneous other round wood with different parameters for density, fraction to long-term storage and lifetime in each category (See Table). The method as outlined in the draft provides an estimate for the net increase in carbon stored in the inventory year (1990 for the comparison here) but a more detailed breakdown can be made and this is shown in Table . The forest biomass uptake rate is as n the IPCC 1996 method. The extra carbon in products from the combination of UK and imported timber was 7.51 Mt a^{-1} and from these products 2.63 MtC a^{-1} were lost immediately and a further 3.57 MtC a^{-1} were lost from products which had been in use from earlier years. A further loss of 0.77 MtC a^{-1} was also estimated from litter remaining in the forest after harvest and a small allowance was made for timber exported as pulp. The net uptake of carbon was hence 5.38 Mt a^{-1} in 1990 the greatest value estimated for that year by the methods compared (Table).

Comparison of methods

The two approaches using the C-FLOW 98 model are directly comparable the difference is simply a matter of adding the uptake of carbon by imported products (0.99 MtC a^{-1} for 1990). The IPCC 1996 Default method provides a net uptake estimate about 25% lower than C-FLOW 98. The most notable difference is however between the estimates from the C-FLOW 98 plus products approach and the IPCC draft products method. This would appear to be to a lower value for carbon being added to the product pool from UK production in C-FLOW compared to the IPCC method based on FAO trade statistics. The model of generation of products in C-FLOW is based on fairly broad assumptions and it would appear that changes in parameter values could be useful.

Monte Carlo analysis of the effect on net uptake of uncertainty in the various parameters in the models of carbon gain and loss by wood products suggests that the most important are the assumed value for mean carbon uptake by growing forests and parameters, particularly density, associated with sawnwood. This reflects the overwhelming importance of sawnwood to the net mass of products and increase in biomass being directly proportional to the assumed uptake rate. Surprisingly the assumptions on the time pattern of loss of product carbon do not appear to be of major importance.

References

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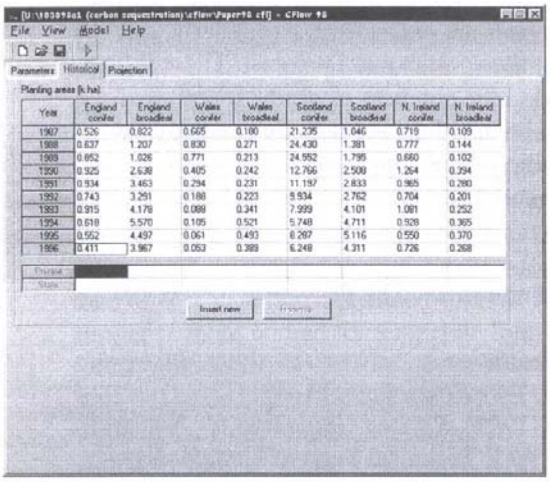
Milne, R., Brown, T.A.W. & Murray, T.D. (1998) The effect of geographical variation of planting rate on the uptake of carbon by new forests of Great Britain. *Forestry* (In press)

Future work 1998/99

- Further work on uncertainty in carbon flux estimates for Forestry
- Detailed comparison of UK wood product modelling by C-FLOW 98 and IPCC methods.
- Collation of land cover and use data from different surveys from 1930 to 1990.
- Construction of method of updating estimates of changes in soil carbon due to Land Use Change based on regularly published statistics, occasional surveys and updating using matrices of area change.

Appendix 1: C-FLOW 1998 screen displays

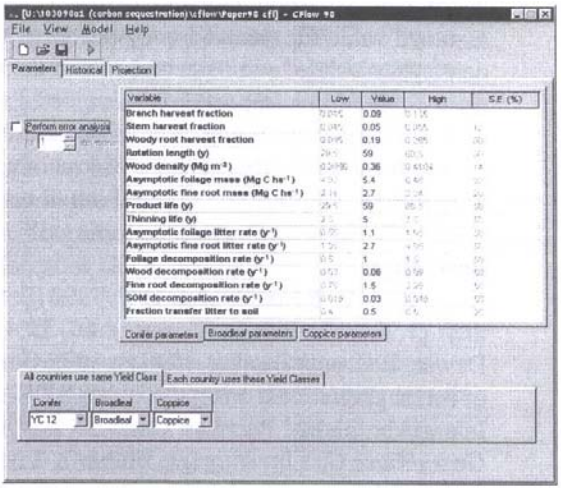
Figure A1-1 Historical planting data



Planting areas [k ha]

Year	England conifer	England broadleaf	Wales conifer	Wales broadleaf	Scotland conifer	Scotland broadleaf	N. Ireland conifer	N. Ireland broadleaf
1987	0.526	0.822	0.665	0.180	21.235	1.046	0.719	0.109
1988	0.637	1.207	0.830	0.271	24.430	1.381	0.777	0.144
1989	0.852	1.026	0.771	0.213	24.552	1.795	0.660	0.102
1990	0.925	2.638	0.405	0.242	12.766	2.500	1.264	0.394
1991	0.934	3.463	0.294	0.231	11.197	2.833	0.965	0.280
1992	0.743	3.291	0.188	0.223	9.934	2.762	0.704	0.201
1993	0.915	4.178	0.088	0.341	7.999	4.101	1.081	0.252
1994	0.618	5.570	0.105	0.521	5.748	4.711	0.928	0.365
1995	0.552	4.497	0.061	0.493	8.287	5.116	0.550	0.370
1996	0.411	3.967	0.053	0.389	6.248	4.311	0.726	0.268

Figure A1-2 Model parameters



☐ Perform error analysis

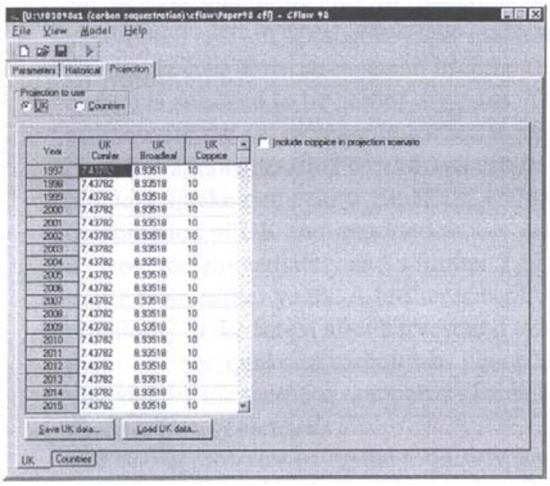
Variable	Low	Value	High	S.E (%)
Branch harvest fraction	[illegible]	0.09	[illegible]	
Stem harvest fraction	[illegible]	0.05	[illegible]	[illegible]
Woody root harvest fraction	[illegible]	0.19	[illegible]	[illegible]
Rotation length (y)	[illegible]	59	[illegible]	[illegible]
Wood density (Mg m⁻³)	[illegible]	0.36	[illegible]	[illegible]
Asymptotic foliage mass (Mg C ha⁻¹)	[illegible]	5.4	[illegible]	[illegible]
Asymptotic fine root mass (Mg C ha⁻¹)	[illegible]	2.7	[illegible]	[illegible]
Product life (y)	[illegible]	59	[illegible]	[illegible]
Thinning life (y)	[illegible]	5	[illegible]	[illegible]
Asymptotic foliage litter rate (y⁻¹)	[illegible]	1.1	[illegible]	[illegible]
Asymptotic fine root litter rate (y⁻¹)	[illegible]	2.7	[illegible]	[illegible]
Foliage decomposition rate (y⁻¹)	[illegible]	1	[illegible]	[illegible]
Wood decomposition rate (y⁻¹)	[illegible]	0.06	[illegible]	[illegible]
Fine root decomposition rate (y⁻¹)	[illegible]	1.5	[illegible]	[illegible]
SOM decomposition rate (y⁻¹)	[illegible]	0.03	[illegible]	[illegible]
Fraction transfer litter to soil	[illegible]	0.5	[illegible]	[illegible]

All countries use same Yield Class | Each country uses these Yield Classes

Conifer	Broadleaf	Coppice
YC 12	Broadleaf	Coppice

Figure A1-3 Projection (UK)

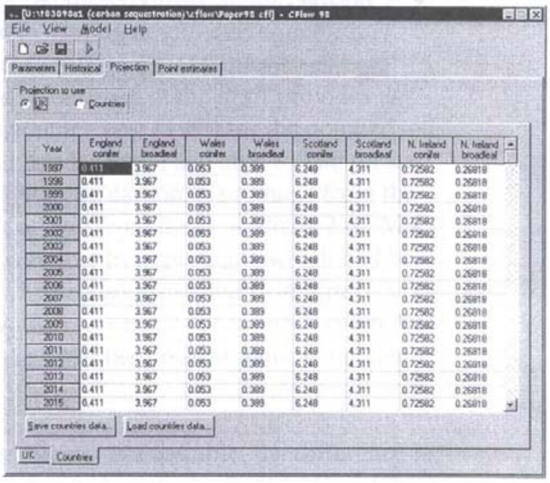
Figure A1-4 Projection (countries)



Projection to use: ● UK ○ Countries

☐ Include coppice in projection scenario

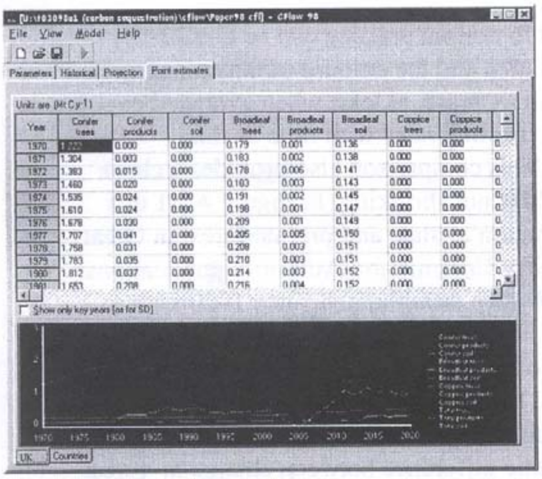
Year	UK Conifer	UK Broadleaf	UK Coppice
1997	7.43782	8.93518	10
1998	7.43782	8.93518	10
1999	7.43782	8.93518	10
2000	7.43782	8.93518	10
2001	7.43782	8.93518	10
2002	7.43782	8.93518	10
2003	7.43782	8.93518	10
2004	7.43782	8.93518	10
2005	7.43782	8.93518	10
2006	7.43782	8.93518	10
2007	7.43782	8.93518	10
2008	7.43782	8.93518	10
2009	7.43782	8.93518	10
2010	7.43782	8.93518	10
2011	7.43782	8.93518	10
2012	7.43782	8.93518	10
2013	7.43782	8.93518	10
2014	7.43782	8.93518	10
2015	7.43782	8.93518	10



Projection to use: ● UK ○ Countries

Year	England conifer	England broadleaf	Wales conifer	Wales broadleaf	Scotland conifer	Scotland broadleaf	N. Ireland conifer	N. Ireland broadleaf
1997	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
1998	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
1999	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2000	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2001	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2002	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2003	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2004	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2005	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2006	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2007	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2008	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2009	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2010	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2011	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2012	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2013	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2014	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818
2015	0.411	3.967	0.053	0.389	6.248	4.311	0.72582	0.26818

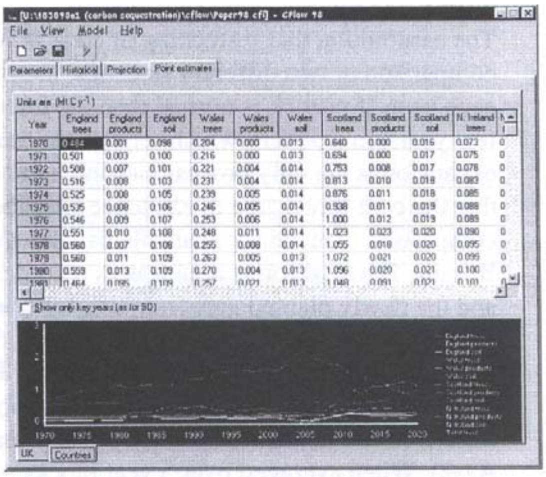
Figure A1-5 Point estimates (UK by type)



Units are (Mt C y^{-1})

Year	Conifer trees	Conifer products	Conifer soil	Broadleaf trees	Broadleaf products	Broadleaf soil	Coppice trees	Coppice products	
1970	1.222	0.000	0.000	0.179	0.001	0.136	0.000	0.000	0.
1971	1.304	0.003	0.000	0.183	0.002	0.138	0.000	0.000	0.
1972	1.383	0.015	0.000	0.178	0.006	0.141	0.000	0.000	0.
1973	1.460	0.020	0.000	0.183	0.003	0.143	0.000	0.000	0.
1974	1.535	0.024	0.000	0.191	0.002	0.145	0.000	0.000	0.
1975	1.610	0.024	0.000	0.198	0.001	0.147	0.000	0.000	0.
1976	1.678	0.030	0.000	0.209	0.001	0.149	0.000	0.000	0.
1977	1.707	0.041	0.000	0.205	0.005	0.150	0.000	0.000	0.
1978	1.758	0.031	0.000	0.208	0.003	0.151	0.000	0.000	0.
1979	1.783	0.035	0.000	0.210	0.003	0.151	0.000	0.000	0.
1980	1.812	0.037	0.000	0.214	0.003	0.152	0.000	0.000	0.
1981	1.653	0.208	0.000	0.216	0.004	0.152	0.000	0.000	0.

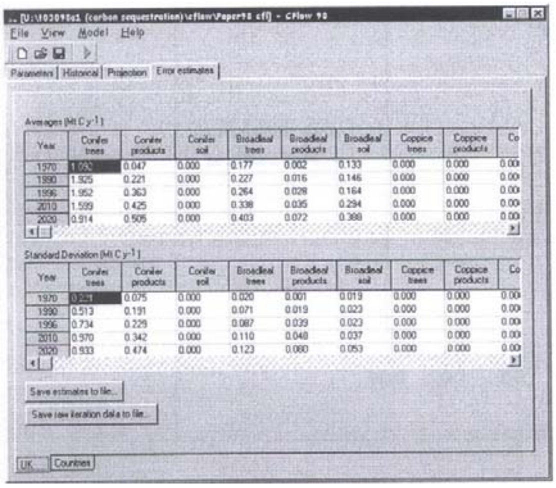
Figure A1-6 (by countries)



Units are (Mt C y^{-1})

Year	England trees	England products	England soil	Wales trees	Wales products	Wales soil	Scotland trees	Scotland products	Scotland soil	N. Ireland trees	N
1970	0.484	0.001	0.098	0.204	0.000	0.013	0.640	0.000	0.016	0.073	0
1971	0.501	0.003	0.100	0.216	0.000	0.013	0.694	0.000	0.017	0.075	0
1972	0.508	0.007	0.101	0.221	0.004	0.014	0.753	0.008	0.017	0.078	0
1973	0.516	0.008	0.103	0.231	0.004	0.014	0.813	0.010	0.018	0.083	0
1974	0.525	0.008	0.105	0.239	0.005	0.014	0.876	0.011	0.018	0.085	0
1975	0.535	0.008	0.106	0.246	0.005	0.014	0.938	0.011	0.019	0.088	0
1976	0.546	0.009	0.107	0.253	0.006	0.014	1.000	0.012	0.019	0.089	0
1977	0.551	0.010	0.108	0.248	0.011	0.014	1.023	0.023	0.020	0.090	0
1978	0.560	0.007	0.108	0.255	0.008	0.014	1.055	0.018	0.020	0.095	0
1979	0.560	0.011	0.109	0.263	0.005	0.013	1.072	0.021	0.020	0.099	0
1980	0.559	0.013	0.109	0.270	0.004	0.013	1.096	0.020	0.021	0.100	0
1981	0.464	0.095	0.109	0.257	0.021	0.013	1.048	0.091	0.021	0.101	0

Figure A1-7 Error estimates (UK by type)



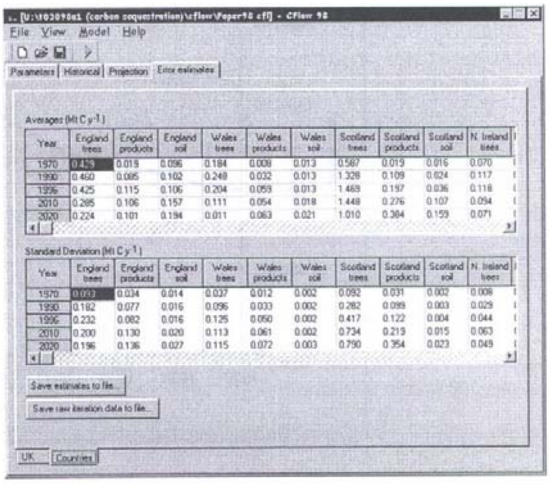
Averages (Mt C y^{-1})

Year	Conifer trees	Conifer products	Conifer soil	Broadleaf trees	Broadleaf products	Broadleaf soil	Coppice trees	Coppice products	Co
1970	1.092	0.047	0.000	0.177	0.002	0.133	0.000	0.000	0.00
1990	1.925	0.221	0.000	0.227	0.016	0.146	0.000	0.000	0.00
1996	1.952	0.363	0.000	0.264	0.028	0.164	0.000	0.000	0.00
2010	1.599	0.425	0.000	0.338	0.035	0.294	0.000	0.000	0.00
2020	0.914	0.505	0.000	0.403	0.072	0.388	0.000	0.000	0.00

Standard Deviation (Mt C y^{-1})

Year	Conifer trees	Conifer products	Conifer soil	Broadleaf trees	Broadleaf products	Broadleaf soil	Coppice trees	Coppice products	Co
1970	0.221	0.075	0.000	0.020	0.001	0.019	0.000	0.000	0.00
1990	0.513	0.191	0.000	0.071	0.019	0.023	0.000	0.000	0.00
1996	0.734	0.229	0.000	0.087	0.039	0.023	0.000	0.000	0.00
2010	0.970	0.342	0.000	0.110	0.048	0.037	0.000	0.000	0.00
2020	0.933	0.474	0.000	0.123	0.080	0.053	0.000	0.000	0.00

Figure A1-8 (by countries)



Averages (Mt C y^{-1})

Year	England trees	England products	England soil	Wales trees	Wales products	Wales soil	Scotland trees	Scotland products	Scotland soil	N. Ireland trees
1970	0.429	0.019	0.096	0.184	0.008	0.013	0.587	0.019	0.016	0.070
1990	0.460	0.085	0.102	0.248	0.032	0.013	1.328	0.109	0.024	0.117
1996	0.425	0.115	0.106	0.204	0.059	0.013	1.469	0.197	0.036	0.118
2010	0.285	0.106	0.157	0.111	0.054	0.018	1.448	0.276	0.107	0.094
2020	0.224	0.101	0.194	0.011	0.063	0.021	1.010	0.384	0.159	0.071

Standard Deviation (Mt C y^{-1})

Year	England trees	England products	England soil	Wales trees	Wales products	Wales soil	Scotland trees	Scotland products	Scotland soil	N. Ireland trees
1970	0.093	0.034	0.014	0.037	0.012	0.002	0.092	0.031	0.002	0.008
1990	0.182	0.077	0.016	0.096	0.033	0.002	0.282	0.099	0.003	0.029
1996	0.232	0.082	0.016	0.125	0.050	0.002	0.417	0.122	0.004	0.044
2010	0.200	0.130	0.020	0.113	0.061	0.002	0.734	0.219	0.015	0.063
2020	0.196	0.136	0.027	0.115	0.072	0.003	0.790	0.354	0.023	0.049

Appendix 2: Restocking of clearfelled forests

The assumption that restocking of clear felled forests in normal practice can be checked by comparison of two different statistics: the total forest area and the amount of new planting in each year. If restock is normal then the forest area will increase, at least when averaged over a few years, in a pattern which reflects the variation in planting rates with time as this expansion is the only process causing a net increase. This comparison also provides a check that the core forest area in existence since before 1920 is not shrinking. In Figure A2-1 this comparison is made for available data for the combination of state and private forest in Great Britain. The total forest area was as recorded in Forestry Commission/Authority publications and the newly planted area from the same sources has been accumulated since 1920 with a starting area based on available data but with a small adjustment to align the two data series to allow easier comparison of their slopes. There is no strong evidence that there have been changes in restocking over the 30 year period shown. This is confirmed by looking at data for the difference in the area planted in each year from the change in recorded total area (Figure A2-2). When averaged over 5 year blocks the arithmetic difference between change in forest area and newly planted area varies around zero but with no clearly identified pattern.

Figure A2- 1: Comparison of accumulated area of new planting with recorded total forest area for Great Britain.

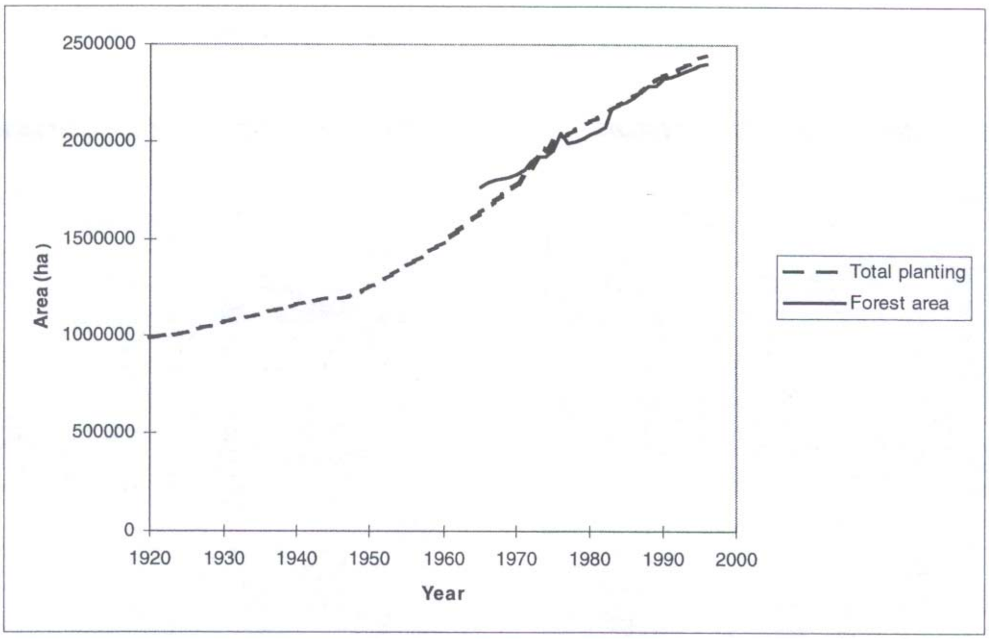


Figure A2-2: Difference between new planting in each year and increase in total forest area. Points are data for individual years and line is average over 5 year blocks.