Estimation of carbon stores and production of carbon density maps for Northern Ireland: progress in the use of data based on CORINE land cover, Soil Survey and the Peatland Survey

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Part 1 Carbon stored in vegetation and its geographical distribution : progress in Year 1

Objectives

1. Estimate the store of carbon in terms of CORINE land cover classes and derive the total vegetation carbon store for Northern Ireland (NI).

2. Map the distribution of vegetation carbon stores, based on mean carbon density per ha for 10 x 10 km grid squares.

Summary

* Vegetation carbon stores are based on the CORINE land cover map The area of NI was extracted from the all-Ireland database; the total area in each CORINE 3rd/4th Level class was obtained.

* Comparison of CORINE classes with land cover classes used in GB, and further calculations for some classes, led to the allocation of a carbon density (tonnes/ha) to each CORINE class. Average carbon densities, weighted by age and species, for conifers and broadleaved forests in 1993 were calculated to be 34 and 62.3 tonnes/ha respectively.

* The total carbon stored in the vegetation of each CORINE land cover class was found by multiplying the area (ha) by the carbon density. Classes were grouped into major vegetation types and class totals were summed to give a total vegetation carbon store for NI of 5.2 Mt (this allows for forests underestimated by CORINE).

* The CORINE map database was intersected with a 10 x 10 km grid to obtain the area of each CORINE class in each grid square. Mean carbon density tonnes/ha was calculated for each square; these values were mapped on a 10 x 10 km grid base, with the outline of NI overlaid.

INTRODUCTION

The Framework Convention on Climate Change commits the UK Government to establish national inventories of greenhouse gas reservoirs/stores and to develop policies to protect and enhance them. Earlier work estimated the carbon stored in vegetation and soils for Great Britain only (Milne 1994; Howard *et al.* 1994). To achieve national coverage in the current inventory, Northern Ireland is included as part of the UK. The first step was to estimate forest carbon stores and fluxes of carbon into/out of the stores, using modelling procedures applied previously to GB (Cannell *et al.* 1995). This paper extends the estimation of vegetation carbon stores to all vegetation types. To be an acceptable part of the UK inventory, it was essential that comparable data sources and the same methods of calculating carbon should be applied as for GB (Milne 1994 and 1995).

Survey data: the use of CORINE land cover for Northern Ireland
NI has land cover data similar to that previously used to calculate carbon stores in GB (Milne 1994), but it is not identical to that currently being used for GB. Surveys, based on stratified habitat sampling of 32 landscape ecological (LE) classes, were carried out for the whole Province in blocks during 1986-1990, by the University of Ulster on contract to Environment Service (Cooper and Murray 1992). Samples were visited on one occasion only (unlike in Great Britain with visits in 1984 and 1990). From this source, carbon stores on the surface in NI could be estimated as for GB previously (Milne 1994), <u>except</u> without knowing changes 1984 - 90.

The current study of GB (Milne 1995) uses extension of LE sample data of the ITE Countryside Survey to the whole area, by classification of satellite image data (Fuller *et al* 1994). For NI a similar approach was taken by developing links between CORINE satellite land cover classes and the GB classes used for satellite data. However, change between 1984 and 1990 remains unavailable.

CORINE land cover
Land cover of the whole of Ireland was mapped on an EU contract following CORINE methodology (O'Sullivan 1995). This required visual interpretation of hard copy images at 1:100,000, derived from LANDSAT TM data in bands 3, 4 and 5 of May 1989/90. Interpretation for the north of Ireland was done by M.M.Cruickshank and R.W.Tomlinson of Queen's University. The land cover polygons interpreted at Level 3 of the CORINE classification (Table 1) were traced onto an acetate overlay from which they were digitised (by scanning) and labelled by the Ordnance Survey (NI). Note that two classes (pasture and peat bogs) were subdivided at a 4th Level outside the CORINE contract and the subdivisions are used in this carbon study. The CORINE map database in vector format is in ARC/INFO.

At Level 3, CORINE has 44 classes, but only those applicable to Ireland are included in the table. Exclusion of the three sea-water classes means that 31 CORINE 3rd Level classes were used for the carbon study. The two fresh water classes (511 and 512) were included as part of the 'land' area. The two classes subdivided at a 4th Level increased the total number of CORINE classes used for the carbon study to 34. As the minimum polygon size allowed is 25 ha, even polygons of 'pure' classes contain impurities of other classes and if 3 or more classes are involved the dominant could be < 50%. In other cases 'pure classes' will not be uniform in land cover. For example, the class of "discontinuous urban areas", used for suburban areas (1.1.2), includes trees, grass and built surfaces. Some agriculture and tree classes are 'mixed' by definition and the proportions of the mix can vary. All these points were considered in devising carbon density factors for CORINE classes.

The accuracy of the CORINE interpretation was tested independently in the project by a verification exercise. For the north of Ireland, the interpretation was found to be about 80% accurate in the east and 70% in the west. The CORINE team regard this as good, but limitations and problems attached to the verification are outlined in the project report (O'Sullivan 1995).

Additional spot checking by the EU technical team in the west found the interpretation to be correct, but the level of accuracy was not reported to the project team. To sum up, the accuracy is considered to be good, but further work is needed on class content and variability. The accuracy appears to be similar to that of the GB satellite land cover map (Fuller *et al.* 1994).

METHODS

CORINE class to Great Britain key cover type (satellite imagery) class links
Links were established by discussion between RM (on GB cover types) and MMC (on CORINE). Discussions were guided by links given in the Countryside Information System for GB. The GB satellite key cover types (17) were used, with knowledge of the allocation of target land cover types (25) to those. For CORINE, class definitions in the CORINE Technical Guide (EU 1992) were used, together with personal knowledge of NI land cover and how that was classified (O'Sullivan 1995). The links established are shown in Table 2.

Table 2. Links between GB key cover types for summary data and CORINE classes

Key cover types (17 classes)	**CORINE classes**
Continuous urban	1.1.1, 1.2.1, 1.2.2, 1.2.3
Suburban	1.1.2
	1.2.4
Tilled land	2.1.1, 2.4.2/2
Managed grassland	1.4.1, 1.4.2, 2.3.1.1, 2.3.1.3/2, 2.4.2/2
Bracken	Included in 3.2.2
Rough grass/marsh	2.3.1.2, 2.3.1.3/2, 3.3.1
Heath/moor grass	3.2.1
Open shrub heath/moor	) 3.2.2
Dense shrub heath/moor	)
Bog	4.1.1, 4.1.2.1
Deciduous/mixed wood	(3.1.1 (broadleaved) (3.1.3 (mixed)
Coniferous woodland	3.1.2
Inland bare	1.3.1, 1.3.2, 3.3.2, 3.3.3, 3.3.4, 4.1.2.2
Saltmarsh	4.2.1
Coastal bare	4.2.3
Inland water	5.1.1, 5.1.2
Sea/estuary	5.2.1, 5.2.2 and 5.2.3.

Note, no links found for CORINE classes 2.4.1, 2.4.3 and 3.2.4.

CORINE classes show similarities but important differences with the classes used for the GB satellite land cover map. Some classes are identical in definition and in other cases, several CORINE classes can be combined into a GB class. A problem arises with CORINE classes that are mixed by definition: 2.4.1, 2.4.2, 2.4.3, 3.1.3 and 3.2.4 and also the mixed class in the 4th Level subdivision of pasture (2.3.1.3). All mixed classes will contain components of two or more GB classes. As well, it was realised that some 'pure' classes include components of land cover with different carbon densities: 1.1.2, 1.2.4, 1.4.1 and 1.4.2. For these and the mixed classes, the proportions of component land cover types were estimated using large scale air photographs in limited areas for which those were readily available. Map sources and local knowledge were also used.

In the CORINE classification, all semi-natural vegetation is allocated to 'pure' classes, eg natural grassland (3.2.1). Such classes may be expected to be less pure and true to their definition, than agriculture and forest where mixed classes are available. It was noted earlier that the minimum polygon size of 25 ha also has implications for purity. With these reservations in mind, for CORINE and GB classes where there was an acceptable link, the carbon density used for the GB class was used also for the CORINE class. This left about a third of the CORINE classes requiring additional work to find a carbon density.

Carbon density of forests in Northern Ireland

Calculations of forest carbon density were made earlier for GB (Milne 1994), using volume and area data up to 1980 and factors for converting volume into carbon, which vary by species and age. Thereby, carbon densities were obtained for major species by age groups and also, weighted averages for each species. Thence, (two) weighted averages were derived for all conifers and all broadleaves in GB, which were applied to total areas of conifers and broadleaves to obtain a GB total carbon stored in forests. Through work on forests in NI as carbon stores (Cannell *et al.* 1995), it became apparent that the species/age structure of forests differed from that in GB. It was decided therefore to calculate mean carbon densities for broadleaved and conifer forests in NI up to a base date of 1993. The following calculations are based only on broadleaves in the Private Sector (where most are found) and conifers in the State Sector (for the same reason). Methods of calculation and the same carbon conversion factors, as used for GB by Milne, were applied to volume and area data to find carbon density.

Broadleaves in the Private Sector. The Private Woodland Inventory, 1975-79 (Graham 1981, Tables 19 and 31) includes volume and area tables for major species in age groups. Data in these tables are rounded to 100 ha for area and 1000 m^3 for volume; small amounts are omitted, which means that some species/age slots have missing area and/or volume data where values would be low. For each year since 1975, the total area of grant-aided private planting was known from Annual Reports of Forest Service, Department of Agriculture for Northern Ireland (DANI) and the Forest Service estimated the likely percentage of broadleaves; volume data were not available. Data from these two sources were used separately and also combined to estimate the carbon density for broadleaved forests in NI. By varying the data input, but using the methods outlined for GB (Milne 1994), four different results were obtained:

1. Inventory data up to 1975; using separate species, but ignoring age/species slots with missing volume and/or area data. This used 85% of the total area of broadleaves. Weighted average carbon density <u>54.7 tonnes/ha.</u>

2. Inventory data up to 1975; all broadleaves together. This used the broadleaved total (100%) for each age group in the area and volume tables. Weighted average carbon density <u>52.5 tonnes/ha.</u> This result is regarded as the most comparable to that of 61.9 t/ha found for GB using data to 1980 but using separate species (Milne 1994). At that date, the average carbon density appears to have been lower in NI.

3. Inventory plus grant-aided planting since 1975; all broadleaves together. This involved increasing the ages of trees, ie moving those planted before 1975 into higher volume/area values. This estimate relates to carbon density in 1993. Weighted average carbon density 68.2 tonnes/ha.

4. The inventory took place between 1975 and 1979, during which losses were noted at a rate of 160ha/year. As 2/3 of the private forest was broadleaved, an approximate rate of loss of 100 ha/year is possible for broadleaves between 1975 and 1979. In recent years, grants introduced for farm woodland maintenance and planting are thought to have reduced the rate of loss (Guyer and Edwards 1988). Therefore it was decided to assume a rate of loss of 100ha/yr for the first half and 50ha/yr for the second half of the years between 1979 and 1993. Thus, for the 14 years since the inventory a total of 1050 ha was subtracted from the area of the oldest class. Weighted average carbon density 62.3 tonnes/ha.

The results of these four approaches are outlined in Table 3. With the omissions in estimates 1, 2 and 3 in mind, it is suggested estimate 4 be used. Therefore, the weighted average carbon density for NI broadleaves in 1993 is 62.3 tonnes/ha.

Conifers in the State Sector. This calculation was based on data supplied by Biometrics Division of DANI for the whole of the state owned conifer area. Data included areas (ha) in the present forest estate of six major species/groups, by 10 year age bands. Volume data (m^3) were given for the same groups. The six species/groups are: Sitka spruce, Norway spruce, Douglas fir, all pines together, all larches together and other conifers. The base year for age was 1993.

Volume data were based on mean volume per hectare from inventory plots located at random. Plots are usually circular, but the shape is amended to exclude roads etc. Therefore the volume data relate to the productivity of an area of continuous tree planting, not to the total forest, which of necessity includes roads, rides and buildings - up to 15% of the forest area. On that basis, for the volume/area ratios required for carbon density, the areas were increased to include roads, etc, in order to represent the total forest area. Volumes were estimated to a minimum top diameter of 7cm, therefore some timber in the tips of older trees and the whole of young trees was omitted. In fact no volume data were supplied for planting since 1980 (21% of the planted area), nor for two groups from the previous decade, yet area data showed trees had been planted. To fill missing slots, timber volume per unit area was estimated to be half that of the preceding/next older decade.

Carbon conversion factors used for GB by Milne include a stemwood biomass factor of 2 for trees up to 20 years old and 1.5 for older trees. The NI conifer data included the following planting year ranges: 1993-1981, 1980-1971, 1970-61, 1960-51, 1950-41, 1940-31, 1930-21, >1921. Therefore the ages are 0-13, 14-23, 24-33 years, etc. For the youngest group a factor of 2 was used, for the next 1.75, then 1.5 through the older groups.

The average conifer forest carbon density (tonnes/ha), weighted by species and age for NI was found to be 34 tonnes/ha (Table 4).

This figure is higher than the mean for GB (21.1), where data up to 1980 only were used (Milne 1994). While conifer forests in NI are relatively young compared with GB (Cannell *et al* 1995), the use of 1993 data means that post-1980 planting is included and forests planted earlier than that date have had an extra 13 years to grow. The latter is the main explanation for the higher carbon density of forests in NI. A rough estimate of the likely density for NI in 1980 found it to be lower than the 21.1 for GB.

The carbon density for mixed forests, in the absence of evidence on their proportions, is taken as the mean of broadleaves and conifers in NI - 48.2 tonnes/ha.

Table 3. Carbon density of broadleaved forests in Northern Ireland.

1. Calculation of carbon density t/ha, Private broadleaves, N.I. up to 1975/9 (Inventory date)

Species Age	0-10	11-20	21-30	31-40	41-45	>45	Net
Oak	-	-	19.3	30.9	-	127.9	107.3
Beech	-	-	-	-	-	151.3	151.3
SAB	9.6	13	31.2	37.1	34.7	69.2	36.2
Alder	-	1.9	26.6	60.7	-	-	23.5
Elm	-	-	-	-	-	125.2	125.2
Scrub	-	5.7	5	3.8	-	5.7	5
Other b'leave	-	15.2	26.6	22.8	-	94.9	25.3
			Average weighted by species and age				**54.7**

Carbon conversion factors for spp used as GB. For alder and scrub used "all broadleaved" factors

Only used age/species slots with both vol and area figs. Noted Figs in Tables were rounded to 100 ha (area) and 1000 cu m (vol)

2. All Private broadleaves together up to 1975/9

	1.63	12.5	28.5	39.2	46.5	113.2	**52.4**

Weighted average 52.4

3. All broadleaves together up to 1975/9 plus grant-aided plant since then - no species separation available.

	1-10	11-20	21-30	31-40	41-50	51-60	61-65	>65
	1.63	12.5	28.5	39.2	46.5	113.2	113.2	113.2

Assumes no increase in t/ha with age beyond what is known through Vol/Area data. Oldest class was pre 1900.

The weighted average is then 68.2

4. It is recorded that during the Inventory (1975-79) trees were being lost @ c100ha per year.

Losses since 1979 estimated @ 100ha/yr for 7 years and 50 ha/yr for 7 years. Grant aided planting as in 3.

Allowing for potential losses, weighted average is 62.3.

Method 4 takes into account the forest structure up to 1975/9, together with planting and losses since then.

That result will be taken as the weighted average carbon density for broadleaves in NI

Table 4. Carbon density of conifer forests in Northern Ireland

Planting year	1993-81	1980 -71	1971- 61	1961- 50	1951 - 40	1941 - 30	1931 - 20	Pre 1920	Net
Species Age	1 - 13	14 - 23	24 - 33	34 - 43	44 - 53	54 - 63	64 - 73	> 73	
All pines	8.7	17.4	26.1	34.3	47.9	63.9	69.6	83.6	26
All larches	10.9	19.1	40	54.2	55.8	59.7	73.4	57.7	38
Douglas fir	23.4	40.9	70.1	79.9	137.8	146	195.4		87.1
Norway spruce	8.1	14.1	43	62.2	73.4	81.1	107.8	76.7	48.7
Sitka spruce	7.6	13.3	43.3	61.9	84.6	91.6	97.2	49.6	31.8
Other conifer	12	21	53.8	67.6	92.8	102.9	111.6	52.4	59.9
All conifers	8.1	14.2	42.6	56.7	75.7	83.2	106.6	62.4	34

Estimated carbon density (tonnes/ha) of coniferous species/groups in Northern Ireland State Forests up to 1993

The average (Net) is weighted by the age distribution of each group.

Calculation of carbon density for CORINE classes which include components of different land cover types

Some CORINE classes include components of different GB classes. Where the component classes have the same carbon density as each other, this does not cause a problem for carbon stores, eg arable land and managed grassland in class 2.4.2 both have a carbon density of 1 tonne/ha. However, in other CORINE classes the land cover components belong to GB classes with different carbon densities. For these CORINE classes a carbon density was calculated on the basis of the proportions of cover types estimated to be present. Carbon densities of the components followed those used by Milne (1994).

Calculations were required for the following:

* *1.1.2: discontinuous urban fabric:* this is used for suburban areas. Even after town parks, playing fields and golf courses exceeding 25 ha are taken out as separate classes (1.4.1 and 1.4.2), suburban areas include built-over surfaces, grass and trees (gardens etc). However, from the satellite image, it is clear that there are differences in the suburban area - some parts have a higher density of non-vegetated surfaces than others. It was necessary to establish these differences if a reasonable estimate of the carbon density was to be applied to this class. Two sources were used to examine the proportions of the surfaces:
(i) a small selection for south Belfast of vertical colour air photographs of 1990 at a scale of 1:3,000
(ii) OS(NI) maps of 1:2,500 scale from the late 1970s

With these sources, a transparent grid was used so that at 1 cm intersections a note was made of whether the land surface was:
(a) buildings, roads, paths and other non-vegetated surfaces,
(b) gardens and other green surfaces,
(c) trees.
The percentage of all intersections falling on each of these surface types was calculated. The sample areas of Belfast were selected from within the cover of air photographs and maps so that they included differing sizes and dates of houses, and also public and private housing. For specific 10 x 10 km grid squares, with distinctive image appearance and following work on their surface types, particular carbon values can be applied, but for all other suburban areas the samples suggest that:-

Surface type	**% cover**	**Carbon value**
Buildings	60	60 @ 0.0 = 0.0
Gardens etc	35	35 @ 1.0 = 0.35
Trees	5	0.5 @ 62.3 = 3.12

Therefore, for <u>class 1.1.2, C = 3.5.</u>

* *1.2.4: airports.* These have built-over surfaces as tarmac and buildings (C = 0), and large areas of grass (C = 1). In the absence of contrary evidence, 50% of each was estimated. Therefore the <u>carbon density is 0.5.</u>

* *1.4.1: green urban areas.* Examination of the occurrences of this class showed that it was used mainly for school and other playing fields greater than 25 ha. As these have sparse tree cover and most of the land cover is grass, a value of <u>C = 1.0</u> is reasonable.

* *1.4.2: sport and leisure facilities.* These included most public parks and golf courses etc. Samples of areas classed as 1.4.2 were examined as to surface cover using the vertical colour air photographs and a transparent grid as for class 1.1.2 above. Additionally, for a large area of 1.4.2 in south Belfast the hectarage of trees was known from the Lagan Valley Regional Park Tree Survey (Tomlinson 1988). For this area, the hectarage in lakes, buildings and roads, and in grass was estimated from 6 inch O.S. maps and a carbon density value

for the area obtained. Using this value and those found for areas of 1.4.2 covered by air photographs, a C =12.0 seemed appropriate.

* *2.4.1: annual crops associated with permanent crops.* This was used for scattered orchards, amongst mainly pasture and some arable fields, in a compact area of North Armagh. Orchard areas were taken from a 1:20,000 topographic map of 1975, and found to cover 27% of the area mapped as 2.4.1. DANI statistics and other sources indicated that between 1975 (1840 ha) and 1990 (1171 ha), the total orchard area in Armagh Local Government District decreased by 36% - i.e. by the date of the satellite scan in 1990 there were less orchards in the area mapped as 2.4.1 than there were at the date of the map. Therefore take 27% for 1975 minus 9.7% (9.7% is 36% of 27%) = 17.3% as orchard in 1990. As there is no known carbon density for orchards, it was decided to use the carbon density of sycamore - ash - birch (SAB) derived from the Private Woodland Inventory data (C = 36) (Table 3). The rest of the area (82.7%) was rated as mixed good/poor grass (C = 1.5). Therefore the overall carbon density for class 2.4.1 is C = 8. SAB could have more carbon than managed orchards (apple trees), because orchards have only one layer of trees which are pruned. On the other hand, the ground layer of permanent grass within the orchards (good/poor) has C = 1.5. Through discussion, it was decided to use the SAB figure for the orchard trees as being the most appropriate estimate available.

* *2.4.2: mix of pasture and arable,* estimated as 50% of each. As both components have a carbon density of 1, that is the 2.4.2 class carbon density.

* *2.4.3: principally agriculture with significant areas of natural vegetation.* Assigning a carbon value to this class is difficult since the components of the land cover and their proportions vary. In an attempt to arrive at a reasonable carbon value, all the 10 x 10 km squares with 2.4.3 in them were extracted from the CORINE database (152 of the 182 grid squares). This showed a range of polygon sizes, from 1.0 ha (possible despite the 25 ha rule because the imposition of the grid lines dissects polygons) to 3,000 ha. A stratified sample was selected to include both large and small polygons spread across NI. In each of the selected grid squares the 2.4.3 polygons were examined on the satellite image and the components listed, e.g. pasture/bog, pasture/trees etc. No attempt could be made to estimate the proportions of the components in polygons because of their intricate mixture. Twelve grid squares were examined; in these the most common mixture was natural grassland/pasture or natural grassland/bog/pasture. This reflects the common location of 2.4.3 around the margins of uplands or around lowland bogs. These locations are amongst the most extensive patches of 2.4.3. A markedly different kind of 2.4.3 was the large area of pasture/natural grassland/overgrown hedges in SW Fermanagh.

Although mixtures of trees/pastures were delimited as 2.4.3, polygons tended to be small and often around incised wooded valleys or in demesnes. Some tree/pasture mixtures occurred around Upper and Lower Lough Erne.

From the samples and more general inspection of the images, together with field knowledge, a value of C = 2.0 for class 243 seems reasonable; it may underestimate the contribution of trees and scrub but reflects the weight of the natural grassland/bog/pasture mix in the overall total of 2.4.3.

* *3.2.4: transitional woodland-scrub.* This class was used for discontinuous trees, as when trees are colonising or regressing (but can be a more stable mix maintained by grazing), against a background of rough grass, estimated as 50% of each. Class 3.2.4 was used also for patchily grown conifer forests on peat bog, but since this is a minority of the class it will be ignored. The trees were given the carbon density for sycamore-ash-birch, C = 36 and the rough grass C = 2, leading to an overall carbon density of 19.

* *2.3.1: pastures.* The Irish 4th Level subdivision was used. 2.3.1.1 is high biomass/good growth; 2.3.1.2 low biomass/poor growth; 2.3.1.3 is a patchwork of each of those in units of less than 25 ha and the mix was estimated to be 50% of each on average. Following the

GB carbon densities, 2.3.1.1 as managed grass has C = 1 and 2.3.1.2 as rough grass C = 2, therefore the mixed class has C = 1.5.

Carbon densities for CORINE classes, derived as outlined in earlier sections, are summarised Table 5.

Table 5. Carbon densities (tonnes /ha) for CORINE classes

Carbon density	CORINE class
0	1.1.1, 1.2.1, 1.2.2, 1.2.3, 1.3.1, 1.3.2, 3.3.2, 3.3.3, 3.3.4 4.1.2.2, 4.2.3. 5.1.1, 5.1.2
0.5	1.2.4
1	1.4.1, 2.1.1, 2.3.1.1, 2.4.2
1.5	2.3.1.3, 3.2.1, 3.3.1
2	2.3.1.2, 2.4.3, 3.2.2, 4.1.1, 4.1.2.1, 4.2.1
3.5	1.1.2
8	2.4.1
12	1.4.2
19	3.2.4
34	3.1.2
48.2	3.1.3
62.3	3.1.1

Distribution of carbon by 10 x 10 km grid squares
Using ARC/INFO, the CORINE database coverage was intersected with a grid coverage to divide the map into 10 x 10 km units. ARC routines enabled the total area (ha) in each CORINE class to be recorded for the squares. Multiplication of these areas by their carbon density factors allowed the mean carbon density per ha for the land area to be derived for each square (all sea-water classes being excluded). The mean carbon densities were allocated to the same class ranges as used for GB and then mapped on a 10 x 10 km grid base, with the boundary of NI overlaid.

RESULTS

Carbon stored by forests in Northern Ireland
The total amount of carbon stored in forests in Northern Ireland is about 3 Mt based on DANI planting data and 2.4 Mt from CORINE data (Table 6). These figures were derived from the weighted carbon densities estimated for conifer, broadleaved and mixed forests, multiplied by the known areas to find the total carbon stored in forests. While the forest carbon density estimates were based only on conifers in the State Sector and broadleaves in the Private Sector, the carbon store estimates must be based on the total forest area. There are two sources for that: DANI planting data (up to 1993) and CORINE data (satellite scan May 1989/90). The DANI-based estimate of total forest area is about 20% higher than that

from CORINE. Three reasons can be found for the lower CORINE estimate. (1) The CORINE interpretation used satellite data of three years earlier than DANI. (2) Young trees are not sufficiently well grown to affect reflectance and be apparent in visual interpretation of the image. (3) Small patches, notably in the Private Sector, will be missed due to the minimum polygon size of 25 ha. While the difference can be explained, the DANI-based figure of 3 Mt must be the more useful estimate. This is less than the 3.8 Mt estimated by Cannell *et al.* 1995 and again the difference can be explained. That estimate was based on modelling from planting year data for all conifers and all broadleaves together and assumed all conifers to be Sitka spruce (Picea sitchensis) of Yield Class 14 and all broadleaves to be beech (Fagus sylvatica) of Yield Class 6. Carbon stores included not only timber, but also litter which is excluded in the present study. These differences in the calculations account for the higher estimate by Cannell *et al.*

Table 6. Comparison of carbon stores using CORINE and DANI data

	Forest area (ha)		Carbon density	Carbon store (Mtonnes)	
	CORINE	DANI	(tonnes/ha)	CORINE	DANI
Conifer	52183	63466	34.0	1.77	2.16
Broadleave	8489	12607	62.3	0.53	0.79
Mixed	2676	2165	48.2	0.13	0.10
Total	63348	78238		2.43	3.05

Conifers in the State Sector

A range of carbon densities was found between species and ages; density increases with age but it is not highest in oldest trees (Table 4). Planting peaked in the 1960s with the next highest annual rate since then, so that in general, young trees with low carbon densities predominate in terms of area and also in the total carbon store.

The dominant species as a carbon store is Sitka spruce. It has a relatively low carbon density because most was planted since 1960, and accounts for a lower % of the carbon than of the area (Table 7). Even with a high density, Douglas fir contributes little to the store, because that species is rare. Norway spruce is relatively old and contributes a large amount of carbon in relation to its area.

Table 7. Conifer Forests in Northern Ireland

	% conifer area	% carbon store	Age weighted carbon density (t/ha)
Douglas fir	1	2	87.1
Norway spruce	6	9	48.7
Sitka spruce	72	67	31.8
All pines	13	10	26.0
All larches	5	6	38.0
Other conifers	3	6	59.9

Note: species/group breakdown is not possible for broadleaved forests.

One explanation for the higher carbon densities in the age classes for conifer species in NI than those for GB in 1980, is that the youngest class covers 13 years in NI while the youngest for GB covered only 10 years.

It was noted earlier that the average conifer carbon density for NI (1993) was higher than that for GB (Milne 1980). This is explained by the continued sequestration of carbon by trees planted before 1980, which will have increased the carbon stored in those trees (Cannell *et al.* 1995).

Broadleaves in NI

Broadleaves are less common than in GB, a higher % are in the Private Sector and there has been a marked increase in planting (using grant-aid) in recent years (Cannell *et al.* 1995). These points have implications for the carbon stores. Most broadleaves are in private ownership and the age distribution shows a generally bi-modal pattern of old and young trees. Limitations of detail in the Private Woodland Inventory and in the record for grant-aided planting since 1979, made it impossible to calculate carbon densities for species by age groups in as much detail as was done for conifers - despite the use of data from different sources (Table 3). However, an estimate was made of the average carbon density for broadleaves in 1980 (estimate 2), for comparison with GB (Milne 1994), which indicated the carbon density density in NI to be lower - 52.4 tonnes/ha in NI compared to 61.9 for GB. The carbon density in NI increased by 1993, for the same reasons as outlined for conifers. With that increase and recent planting (i.e. young trees), and despite likely losses of older trees since 1979 (incorporated into the 1993 broadleaved carbon density estimate) the carbon store of broadleave forests appears to have increased from 0.64 Mt in 1979 to 0.79 Mt in 1993. This is based on the different age weighted carbon densities and areas of trees at these dates.

The difference between the DANI- and CORINE-based estimates, of both the area and carbon store of broadleaves, is almost twice the difference for conifers (Table 6). The explanation includes the recent surge in planting of broadleaves (Cannell *et al.* 1995), especially of small areas in the Private Sector. Evidence of the latter is found in that areas down to 5 ha were included in the Inventory (1975 - 79) and the Annual Reports of Forest Service show that since 1972 the average area planted with grant aid was less than 5 ha (by dividing the total area of new grants by the number of grants). Both of these sources indicate small areas of broadleaves which would be missed by CORINE. Recently planted/young and older forests would have a lower and higher carbon densities respectively, than the average.

Carbon stored by CORINE classes

It has been noted that CORINE underestimates the forest area compared with DANI data and that this discrepancy can be explained. Nevertheless, according to the CORINE data, forests occupy only 4.6% of the land area but account for 53% of the vegetation carbon store - because of their high carbon densities (Table 8). Other classes which include trees as a component of the land cover also contain higher % carbon store than their % area. The % forest cover according to DANI statistics is higher at 5.8%, but it is clear that forests occupy a smaller % of the land area than in GB (Cannell *et al.* 1995). Agricultural land occupies a larger % area and accounts for a larger % of the carbon in NI than in GB (Table 9). Built-over and other bare surfaces are less common in NI. Within the forests, conifers are relatively more important in NI than in GB.

Forests missed by CORINE will have replaced classes of land cover with lower carbon density, such as poor pasture, natural grassland and peat bog - about carbon density 2 (Table 5). DANI statistics show 14,890 ha more of forests than CORINE (Table 6). The age and species composition of these forests is unknown but some estimate can be made of the possible additional carbon store. If it is assumed that the missing forests include both conifers and broadleaves, and also young and old trees, then the carbon density for mixed forests could be applied to the missing area. Substituting that for the lower carbon density land cover, calculations indicate that the total carbon store would then rise from 4.6 Mt (Table 8) to 5.2 Mt carbon in the vegetation of NI.

Table 8. Vegetation carbon stores (NI) by CORINE classes					
CORINE class	Area (ha)	%/NI	C/t/ha	Carbon(tonnes)	% C
1.1.1	5327.9	0.39	0	0	
1.1.2	30649.9	2.26	3.5	107274.65	2.35
1.2.1	3476.3	0.26	0	0	
1.2.2	642.3	0.05	0	0	
1.2.3	352.8	0.03	0	0	
1.2.4	1201.1	0.09	0.5	600.55	0.01
1.3.1	2465	0.18	0	0	
1.3.2	146.6	0.01	0	0	
1.4.1	897.6	0.07	1	897.6	0.02
1.4.2	4132.5	0.30	12	49590	1.09
2.1.1	32176.9	2.37	1	32176.9	0.71
2.3.1.1	427323.8	31.52	1	427323.8	9.37
2.3.1.2	72692.9	5.36	2	145385.8	3.19
2.3.1.3	262491.1	19.36	1.5	393736.65	8.63
2.4.1	6363	0.47	8	50904	1.12
2.4.2	142960.3	10.54	1	142960.3	3.13
2.4.3	62357.7	4.60	2	124715.4	2.73
3.1.1	8489.2	0.63	62.3	528877.16	11.59
3.1.2	52182.9	3.85	34	1774218.6	38.89
3.1.3	2676	0.20	48.2	128983.2	2.83
3.2.1	53054.9	3.91	1.5	79582.35	1.74
3.2.2.	32468.4	2.39	2	64936.8	1.42
3.2.4.	12925.6	0.95	19	245586.4	5.38
3.3.1.	1248.6	0.09	1.5	1872.9	0.04
3.3.2.	0		0	0	
3.3.3.	181.4	0.01	0	0	
3.3.4.	0		0	0	
4.1.1	1830	0.13	2	3660	0.08
4.1.2.1	129117.3	9.52	2	258234.6	5.66
4.1.2.2	3369.8	0.25	0	0	
4.2.1	78.3	0.01	2	156.6	
4.2.3	2464	0.18	0	0	
Total	**1355744.1**	**100**		**4561674.26**	**100**
C/t/ha: carbon density in tonnes per hectare					
%C: % of carbon store in each land cover class					

Table 9. Vegetation carbon stores (Northern Ireland) by major cover types

MAJOR COVER TYPE	Area(km)	Area %	Carbon(Mt)	Carbon %
Built up	98	0.7	0	0
Suburban	369	2.7	0.16	3.5
Tilled	1037	7.6	0.1	2.3
Managed grass	6300	46.5	0.63	13.8
Rough grass/marsh	2793	20.6	0.56	12.2
Moorland grass	531	3.9	0.08	1.7
Heath	325	2.4	0.06	1.4
Bog	1343	9.9	0.26	5.7
Broadleave forest	161	1.2	0.8	17.6
Conifer forest	522	3.8	1.77	38.9
Mixed forest	27	0.2	0.13	2.8
Inland bare	53	0.4	0	0
Total	13559		4.55	

Carbon in Vegetation Cover Groups

Cover Group	Area(km)	Area %	Carbon(Mt)	Carbon %	GB % carbon
Agricultural	10128.3	74.7	1.33	36.3	9.6
Semi-natural	2540.8	18.7	0.57	11.4	9.8
Forest	698.1	5.1	2.7	52.3	80.1
Non-vegetated	190.3	1.4	0	0	0
Total	13557.5		4.6		

Note: 324(transitional woodland) is divided between broadleaved forest and rough grass in the upper table and between agriculture and forest in the lower table. 241 is divided between broadleaved forest and managed grass in the upper table and included in agriculture below.

Forest type	Area (ha)	Area %	Carbon tonnes	% carbon	GB% carbon
Broadleaved	8489	0.6	52887	11.6	47.3
Conifer	52183	3.8	1774219	38.9	24.8
Mixed	2676	0.2	128983	2.8	8.5

Geographical distribution of carbon stores in vegetation per 10 x10km grid square
The following points concerning the distribution can be seen in Figure 1:

Squares where the mean value >= 8 tonnes/ha - all occur where there is extensive planted coniferous forest.

Squares with mean value 6 - 7.9 tonnes/ha - are found mainly where coniferous forest is patchy and/or less extensive. An exception is square 340380 where the land area has a number of demesnes and parks with mature broadleaved woodland.

Squares with a mean value 4 - 5.9 - some of these contain small coniferous forests, as for example in the north-west. Others, for example around Lough Erne in the south-west, have patches of broadleaved woodland. The Greater Belfast area in the east has a relatively high value due to trees in public parks, golf courses and gardens of large houses. South of Lough Neagh the one square in this class is explained by the presence of apple orchards.

Squares with a mean value 2 - 3.9 - occur in marginal lands and uplands where woodland and forest patches are found associated with extensive peatland.

Squares with mean value 0 - 1.9 - these squares are in the remaining lowland where pasture is dominant.

DISCUSSION

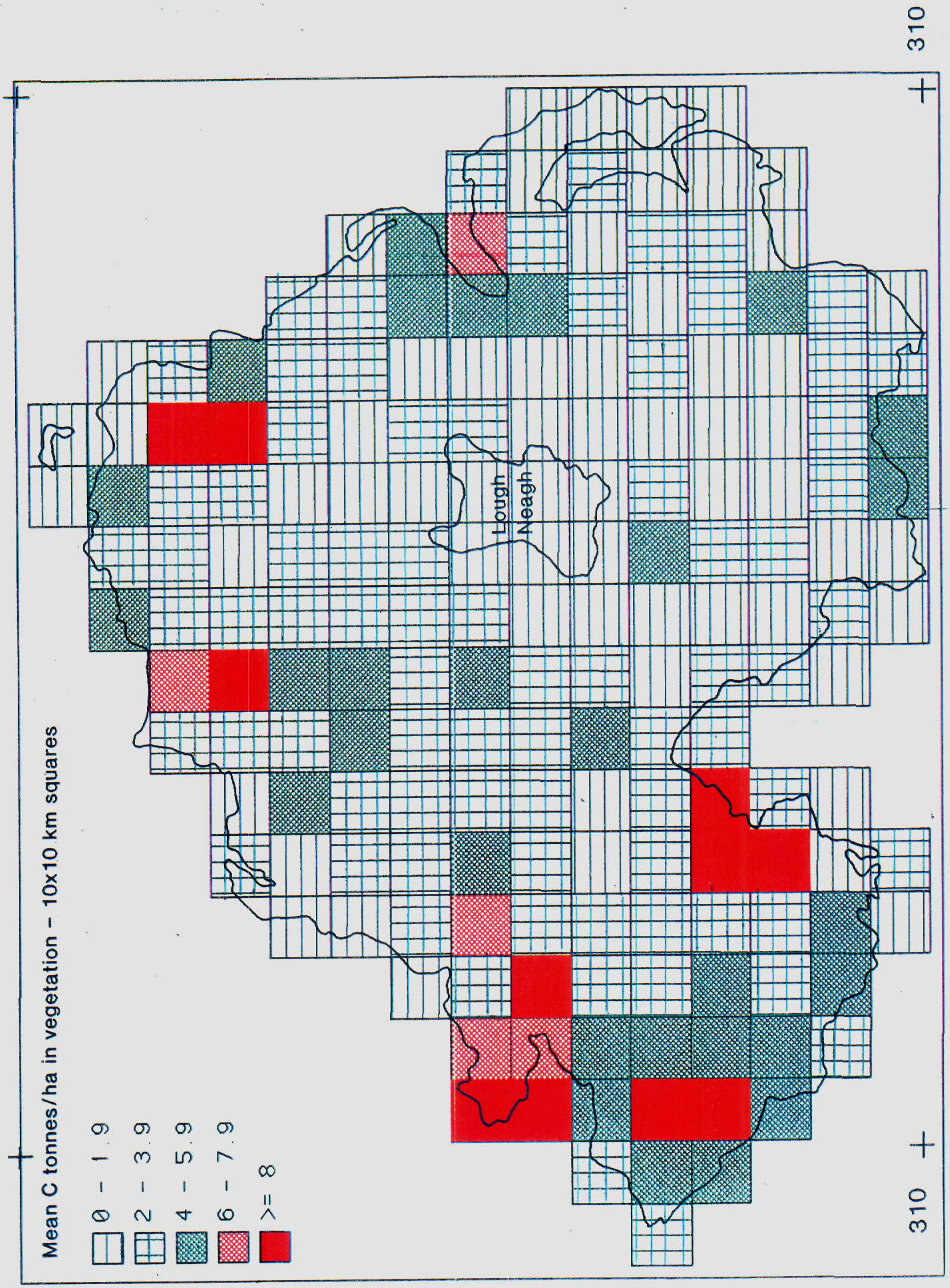
Successful application of CORINE land cover
Links were found between CORINE and GB land cover classes and carbon density factors were devised for the CORINE classes, but otherwise the same methods of calculating carbon stores were used as for GB. These links and densities led to the successful use of CORINE for estimating vegetation carbon stores in Northern Ireland. On this basis, the estimation of vegetation carbon stores could be further extended into European Union countries where CORINE land cover data are available.

Validity of carbon density estimates
Carbon densities were related to those used by Milne for GB (1994 and 1995). Adger *et al.* (1991) refer to higher densities based on experimental sites, but questions arise as to whether vegetation in the "real world", would have such densities. It was assumed that the carbon conversion factors for calculating forest carbon density from timber volumes in GB would apply in NI, but this assumption was not examined critically.

Conflicting forest carbon estimates
Three different estimates have been made for total forest carbon stores and these can be explained. However, this highlights the importance of knowing the methodology and the data basis of any carbon density or total carbon store estimate - before comparisons between GB and NI or between countries are made. Like can only be compared with like; understanding change over time similarly requires caution.

Exclusion of water classes
Inland water was regarded as containing no carbon (C = 0). As NI has many lakes, some very large - Lough Neagh and Upper and Lower Lough Erne - the carbon density of some 10 x 10 km grid squares was reduced. Knowledge of the existence of the lakes should be known to any reader of the map. One could question whether fresh water should be assumed to be devoid of life, ie carbon.

FIG I



Mean C tonnes/ha in vegetation – 10x10 km squares
0 - 1.9
2 - 3.9
4 - 5.9
6 - 7.9
>= 8
Lough Neagh
310
310

Work to be done in Year 2 (1995 - 6)
The aim of estimating vegetation carbon stores and mapping their distribution has been largely achieved in Year 1, so the aim in Year 2 will to improve the result in two ways. *First,* whilst much discussion took place on the carbon densities for CORINE classes, it was noted that basic scientific data on carbon densities for vegetation are limited. Notably, there are generalisations in Olsen (1983) as a major source and densities based on experimental sites as used by Adger *et al.* (1991) may not be representative of the wider, probably less well managed countryside. Discussion will be required with ITE as to whether the carbon densities for land cover classes used here can be given more sound support or whether some revisions should be made. Work in progress by ITE to convert the satellite land cover map of GB to a CORINE map may offer further insights into class links.

Second, it will be necessary to bring together the NI map with that of GB, at the same scale and on one sheet. This, together with the use of 10 x 10 km grid squares will present problems of legibility for a density shaded map printed at a small scale. Discussion with ITE will be used to resolve this problem.

The class intervals used for the map impose another level of generalisation on the density data. A frequency distribution with a class interval of one provides more detail; 73% of the squares have values between one and four, very few are below one and only 9% are above six.

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Part 2 Carbon stored in soils and its geographical distribution: progress in Year 1

Objectives

1. Estimate the mean carbon density for each soil type/series and derive the total soil carbon store for Northern Ireland (NI).
2. Map the distribution of soil carbon stores, based on mean carbon density per ha for 10 x 10 km grid squares.

Summary

* As soil maps at 1:50,000 have been published only for the eastern half of NI, work has been confined to that area (Figure 1).

* For each 1 x 1 km grid square, dominant soil, dominant vegetation and peat depth were estimated, and compiled in 10 x 10 km blocks. The dominant soil type/series was read from the soil map (domsoil). CORINE land cover classes were grouped into 5 dominant vegetation types (domveg); this was recorded for the area of the domsoil in each 1 x 1 km square. For squares with peat dominant, the depth was estimated to the nearest half metre, from a range of sources.

* For the area of Soil Sheet 21 (Figure 1), soil analytical data were obtained. For mineral soil types (1), bulk density, carbon content and depths of both topsoil and subsoil were supplied by the Soil Survey of NI. For peat (2), the revised estimates used in GB were adopted - in the absence of such data for NI. (1) and (2) were used to calculate soil carbon density/hectare, to be applied to all 1 x 1 km domsoil grid records.

* For each 10 x 10 km area, the mean carbon density was calculated and also the total carbon stored in the soils.

* In Year 2 the methodology will be applied to all of Northern Ireland.

INTRODUCTION

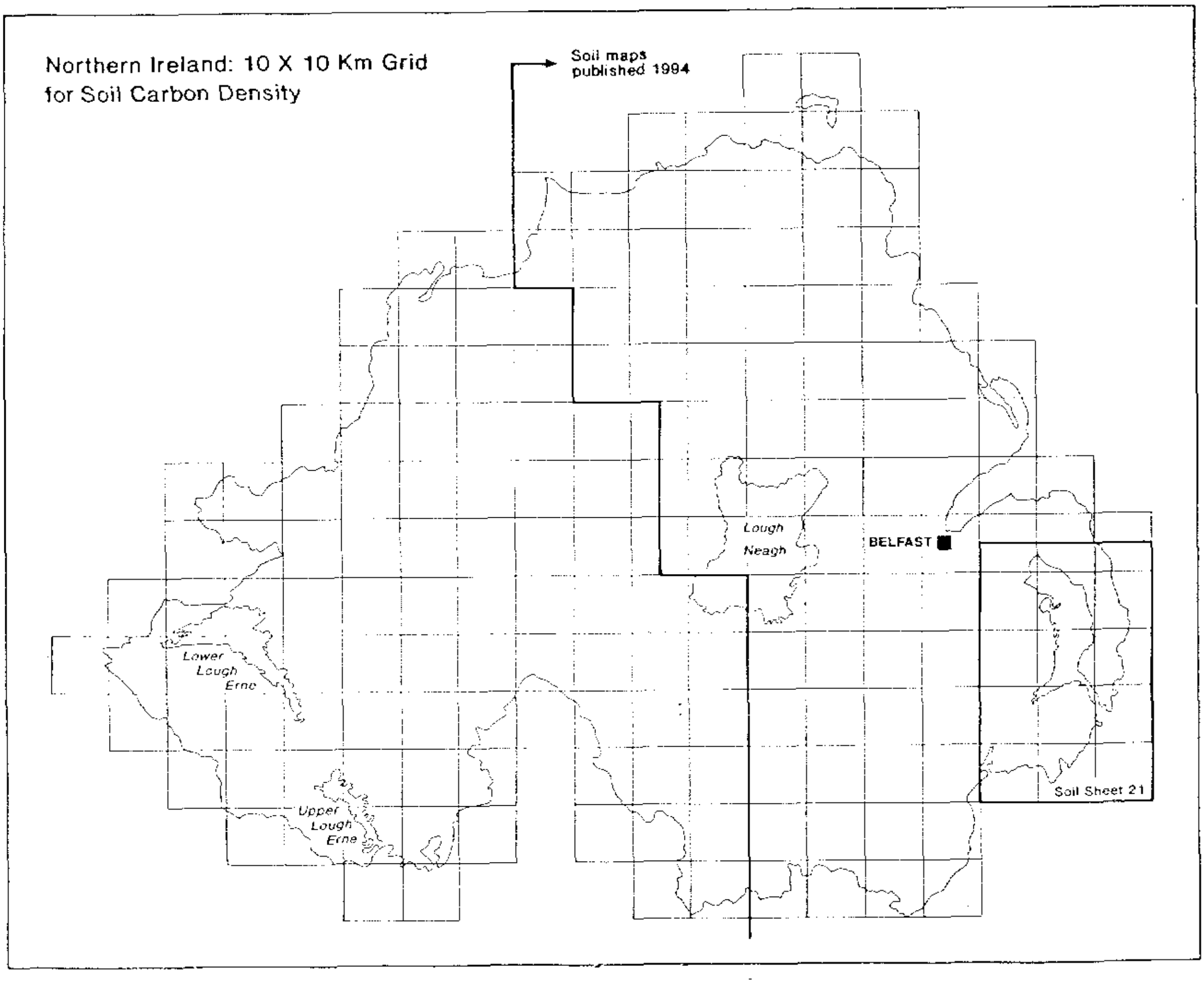
Previous work on soil carbon density and stores was confined to Great Britain (Howard *et al.* 1994). To enable a national inventory to be achieved, NI is now included and for comparability with GB it is essential that the same methodology is applied. A Soil Survey by the Department of Agriculture for Northern Ireland (DANI) is nearing completion. Nine soil maps at 1:50,000 were published in May 1994 and cover the east (Figure 1); field survey of the remainder of the Province was completed by December 1994. However, soil analytical data were not readily available for this first year of the carbon study, even for the east. It was decided to request analytical data only for the area of Soil Sheet 21, as a pilot attempt to calculate carbon density and to reveal problems which need to be solved before the rest of NI is tackled in 1995-6.

For a given soil type, the carbon content varies in relation to the vegetation cover (Howard *et al.* 1994). Accordingly, a soil type should be divided into 4 or 5 variants on the basis of its dominant vegetation cover (domveg). While in NI it is impossible to use the same source for land cover as in GB, domveg can be found from an alternative source - the recently completed CORINE land cover project (Ireland). That was used also in the study of vegetation carbon stores (Part 1). In discussion between MMC and RM, the CORINE classes were grouped into domveg types similar to those used for GB. While in theory this is correct for comparability, it raises two problems in NI: (1) there are almost no analytical data other than for soils under pasture and (2) there is not a clear distinction between pasture and cropped land.

Data sources

Soil Survey of NI. It is planned to publish all the Soil Survey maps of Northern Ireland by Easter 1995. They are currently being digitised and final copy is being produced by the Ordnance Survey (NI). A map database will be available in addition to printed copies of the maps at 1:50,000. There will be 17 maps to cover NI, and presently only maps for the east have been published. Therefore soil carbon work was restricted to that area in 1994 - 5. A wide range of soil properties will be analysed for about 400 pits, based on a 5 x 5 km grid, as well as a more restricted range of properties at additional sites. It is expected that because of the diversity of both geology and topography about 250 soil types/series will be found in the relatively small area of NI. By early 1995 analytical data were available for only a limited number of sites; this led to the decision that only for the area of Sheet 21 (Figure 1) would an attempt be made to calculate mean carbon density for soils. The sheet was extended by 5 kms on the northern side to include the whole of 10 x 10 km grid squares.

Figure 1



Sources used for peat depth and carbon density. Several postgraduate theses, completed at Queen's University (QUB), record peat depth at grid referenced locations. Notable is the MSc by K.W.W. Double in 1954, which surveyed depths of all the larger bogs with a view to commercial fuel exploitation; four other theses record depths at sites of palaeoecological investigations (Goddard, I.C. 1971, Goddard, A. 1971, Francis 1987 and Hanna 1993). Peatland in NI was surveyed by QUB on contract for Environment Service, DoE in 1987 (Cruickshank and Tomlinson 1990). Peatland was mapped from air photographs held in the library of the Ordnance Survey (NI), dating mainly between 1975 - 83. Original copies of the 1:20,000 maps, retained by QUB, were readily available and permission was given by Environment Service for this earlier work to be used for the carbon stores. QUB also completed a study of peat extraction from blanket bogs for DoE in 1990 (Cruickshank *et al.* 1991), which was later extended independently to cover lowland bogs (Cruickshank *et al.* 1995). From ground truthing the Peatland Survey and the peat extraction work, extensive field knowledge of peat bogs was acquired. This, together with consultation of the peatland maps, enabled estimation of peat depth in areas not covered by the postgraduate theses.

There are few records for peat bulk density and carbon content in NI. Previous estimates of these for GB (Howard *et al* 1994) were revised by ITE during 1994 - 5; the revised estimates were used for peat in the area of Soil Sheet 21.

Corine land cover. Overlay maps and satellite images at 1:100,000 from the CORINE land cover project in Ireland were used to find the dominant land cover. The 3rd Level CORINE classes were combined into 5 domveg classes as used for GB. Maps and images, read together, were the source for domveg on the domsoil in each 1 x 1 km grid square.

Grouping of CORINE classes into 5 dominant vegetation types for soil carbon

Agriculture	2.1.1, includes winter sown arable crops and bare soil, some of which will be for reseeding grass as well as for arable crops. 2.4.2, mix of arable (as 2.1.1) and pasture, some being reseeded. The image was consulted for the domsoil area to find out whether arable or pasture was dominant. Only if the former, was it classed as agriculture/tilled.
Pasture:	2.3.1, pasture (includes managed grass, often reseeded in a rotation including an arable crop) 1.4.1, green urban areas (includes playing fields) 1.4.2, sport and leisure (includes golf courses, town parks) 2.4.1, if pasture was dominant in the area of the domsoil 2.4.2, (ditto) 2.4.3, (ditto)
Trees:	2.4.1, if orchard (ditto) 2.4.3, if trees (ditto) 3.1.1, broadleaved 3.1.2, conifer 3.1.3, mixed 3.2.4, transitional woodland-scrub
Semi-natural:	2.4.3, mix of agriculture and semi-natural vegetation. If semi-natural vegetation was dominant in the area of the dominant soil. 3.2.1, natural grasslands 3.2.2, moors and heathland 3.3.1, sand dunes 3.3.3, sparsely vegetated 4.1.1, inland marshes (fens) 4.1.2, peat bogs 4.2.1, salt marshes
Other: (No vegetation)	1.1.1, continuous urban 1.1.2, discontinuous urban 1.2.1, industrial, commercial 1.2.2, roads/railways and associated land

/continued

1.2.3, sea ports
1.2.4, airport
1.3.1, quarry
1.3.2, dump (landfill)
3.3.2, bare rocks
3.3.4, burnt
4.2.3, intertidal flats

This dominant vegetation type allocation involved decisions on some mixed classes: 2.4.1, 2.4.2 and 2.4.3. For these, the image was inspected to determine which component class was dominant in the area of the dominant soil in each 1 x 1 km square.

Dominant soil (domsoil) and dominant vegetation (domveg)
Domsoil. The dominant soil type (combination of profile type and parent material) in each 1 x 1 km grid square was estimated visually from the nine published soil maps of the east. Records were compiled in 10 x 10 km blocks; there are 83 of these in the east, out of a total of about 182 for all NI.

Domveg. CORINE land cover maps, each overlaid on its LANDSAT TM image, were consulted. The domveg type was recorded for the same area as the dominant soil in each grid square. Some mineral soil types were found to have several different vegetation types. Following the methods used for GB domveg should influence the choice of bulk density, % carbon and depth data for the soil type. For peat, land cover was recorded as either agriculture or semi-natural (as Howard *et al.* 1994).

Peat depth
The Soil Survey records peat where the organic layer exceeds 0.5m. Only grid squares shown on the soil maps as having peat dominant were taken as peat for the present study. Therefore some squares with peat(land) according to CORINE and/or the Peatland Survey were not recorded as peat for the carbon study. Conversely, some squares with reclaimed peat >0.5m (in agricultural use) had not been recognised as peat by the other surveys, but were mapped by the Soil Survey and so were recorded as peat.

For grid squares with peat dominant and surveyed by Double (1954), that source was used for peat depth. For most of the 16 sites examined by Double in the east, there were many depth soundings, often on transects; all soundings in each grid square were used to calculate a mean depth which was accepted as still present, unless it was known from field knowledge to be a location of large scale peat extraction. In such a case, a generalised estimate of loss of depth due to extraction was made. The four other theses yielded depths at point locations; these were used to estimate depth in adjacent areas. For all <u>other</u> squares where peat was dominant, evidence of peat depths in the theses was combined with field knowledge and consultation of the Peatland Survey maps to estimate the likely mean peat depth. Peat depths were recorded on the data sheets to the nearest 0.5m.

Soil analytical data and calculation of carbon density tonnes/ha
As data are not readily available at this stage, the Soil Survey were asked to make the best estimates of the required properties for all soil types on Sheet 21 - bulk density (BD), carbon content (C) and depth (D). Bulk density in gms/cc is <u>Field dry bulk density</u> and not the alternative stone free/fine earth/<2mm bulk density. Carbon content is the % dry weight by loss on ignition. Depth was given for both the topsoil and subsoil where relevant (rankers and a minority of other soils are not so divisible). While analyses were requested for vegetation variants of each soil type, almost all those supplied were for pasture. Maximum depth allowed for deeper soils was 100 cms as in GB, but only 60 cms for Shallow Brown Earths.

As it was only possible to obtain analytical data for the area of Sheet 21 (Figure 1), no attempt can be made from the first year of work to show the distribution of soil carbon on a 10 x 10 km grid map.

RESULTS

For the whole of the east, where soil maps have been published
The dominant soil was recorded as the most extensive soil type for each 1 x 1 km grid square and vegetation was recorded for the same area. Mean peat depth was estimated for those 1 x 1 km squares with peat dominant according to the Soil Survey. Records were compiled in 10 x 10 km data sheets.

For the area of Soil Sheet 21
BD, %C and D were supplied for both the top and subsoil of all the soil types that had been recorded for 1 x 1 km grid squares. Carbon density (tonnes/ha) was calculated for each soil type and entered for each 1 x km square; mean carbon density and total soil carbon were calculated for 10 x 10 km areas. This is a lowland area of mineral soils on mainly Silurian shale and shale till parent materials. Being in the drier east of NI peat is rare (only 7 out of the c. 800 1 x 1 km grid squares had peat dominant and that was shallow). While 23 different soil types were found, 75% of the records were for 4 soil types.

Major influences on the mean carbon density of 10 x 10 km squares were the proportion of grid squares that were urban or with peat dominant. Urban areas (C = 0) reduced the density while peat and organic alluvium increased it. Some difficulty was found in applying the revised peat carbon density estimates. The peat in this area comprises the basal layers of cut-over basin bogs and was estimated to be about 1 metre deep - from peat bogs which may have been 2 - 3 metres deep before cutting. The supplied data gave total carbon density/ha for peat 3 metres deep under semi-natural vegetation and 2 metres deep under agriculture or pasture. The pattern of increase of carbon density with depth given for blanket peat was used to estimate a carbon density of the remaining bottom metre. It was assumed that where natural vegetation remained, the site could have been wetter and the peat deeper (3 m); if now under agriculture or pasture, the site could have been drier and the peat less deep (2 m). In this way a carbon density (tonnes/ha was estimated for peat 1 m deep. For organic alluvium on similar basin sites, since the maximum depth of organic material allowed before classification as peat is 0.5 m, half the density for peat was used - again taking into account the present vegetation as for peat.

Analysis of the vegetation records for all the 1 x 1 km squares of Sheet 21 revealed pasture to be the predominant land cover (Table 1).

Table 1. Analysis of domveg for Sheet 21

	%
Pasture	70
Tilled	23
Semi-natural	5
Trees	2

The total number of 1 x 1 km records: 819

The mean carbon density (tonnes/ha) for each 10 x 10 km square is the sum of all the 1 x 1 km carbon densities, divided by the number of 1 x 1 km grid squares (Table 2).

Table 2. Mean carbon density (tonnes/ha) for 10 x 10 km grid squares of Sheet 21

102.7	161.2	105.3
141.3	127.3	130.2
150.3	138.9	145.2
158.4	144.7	156.7
175.0	151.0	

The total carbon stored in each 10 x 10 km square was found by multiplying the mean carbon density (tonnes/ha) by the number of 1 x 1 km grid squares (with land) within the 10 x 10 km square (Table 3).

Table 3. Total carbon store (tonnes) for 10 x 10 km grid squares of Sheet 21

1,006,460	1,418,470	168,480
1,384,980	636,500	637,980
1,502,920	888,960	755,040
1,583,790	1,418,060	266,390
910,190	588,900	

The total carbon store in each 10 x 10 km square is not only influenced by the carbon densities. Several such squares on Sheet 21 include some 1 x 1 km squares entirely of sea, which do not yield any carbon for the total carbon store of the 10 x 10 km area. This explains some of the low values in Table 3.

It was decided to record domsoils for all 1 x 1 km grid squares with some land, even where that was only a small % of the square. In the calculation of total carbon stored it was assumed that the whole square was occupied by land. This has inflated the estimate of total carbon for some 10 x 10 km squares.

DISCUSSION

Is there real advantage in subdividing soil types by vegetation?

It seems to be difficult to separate pasture and tilled land in NI in the same way as for GB. While some permanent pasture is maintained only by grazing, it is common to re-seed pasture/grass (fertilisers and slurry are commonly applied), often in a rotation of up to 5 years, which will include an arable crop. The grass is either grazed or cut up to 3 times a year for silage. Such "pasture" could be regarded as cropped grass. Recent DANI Annual Statistics record that 2/3 of pasture is > 5 years old, which could suggest that it is not re-seeded so frequently; this would include all the CORINE 3rd Level pasture class (2.3.1). half the mixed pasture-arable class (2.4.2), natural grassland(3.2.1) and some peatbog (4.1.2). The 4th Level subdivision of pasture in CORINE (See Part 1) might be used to identify the more productive pasture (2.3.1.1, half 2.3.1.2 and half 2.4.2) as likely to be regularly re-seeded, but at present insufficient field survey has been done to establish the content of these CORINE classes. However, a question remains as to whether there is a significant difference between pasture (as defined in CORINE) and tilled land.

A further difficulty is that the Soil Survey were rarely able to dig sample pits in arable fields and in the Sheet 21 area have no analytical data for those. Neither will there will be many records for soils under semi-natural vegetation or trees, because being funded by the Department of Agriculture, Soil Survey efforts have concentrated on agricultural land. However, analysis of domveg records for all the 1 x 1 km squares on Sheet 21 shows pasture to be dominant (Table 1), despite the fact that this is one of the two areas in NI with a high concentration of arable/tilled land. Overall in NI, pasture is 83% of the agricultural land according to CORINE data (pasture is taken as all of class 2.3.1 and the pasture components of 2.4.1 and 2.4.2); this excludes pasture on heath, natural grassland and peat bogs. Lack of analytical data for soils under semi-natural vegetation and trees will become a greater problem in the uplands and west where these cover types are more extensive.

In the study of Sheet 21, domveg was ignored; the carbon density for the soil type under pasture was applied to the same soil under other vegetation. For reasons outlined in the previous two paragraphs, this may not be a serious deficiency. This issue will be discussed with ITE. If, for comparability with GB, it is decided that in further work account must be taken of domveg, one solution could be to estimate the likely scale of differences in soil carbon density between pasture, crops and semi-natural vegetation based on differences in GB. However, the England/Wales and Scotland average carbon densities for major soil groups (Milne, private communication) do not agree in either the level of carbon or the pattern of differences between the domveg types (a breakdown of the groups into soil types would be more informative, as these have been used in NI). Discussions should also consider whether some of the pasture should be classed as "tilled" and the feasibility of identifying that. Discussion is needed with ITE before further work is done in NI.

Limited availability of bulk density analyses

The Soil Survey will have limited bulk density records, but there will be soil particle size analyses for other sites. A request will be made to SSLRC to obtain the regression equations which allow BD to be estimated from those - as was done by SSLRC and also MLURI in the previous study of soil carbon in GB (Howard *et al.* 1994). It will be necessary to consider whether equations based on data for English soils would be applicable to NI soils. If that suggests problems, then the Soil Survey (NI) will consider the possibility of developing a relationship between bulk density and particle size analysis for NI, i.e. their own version of the regression equations.

Further advice is needed from ITE on the BD and %C to be applied to peat in NI. The pilot study of Sheet 21 used an ITE revision of earlier Scottish estimates. It was assumed that they would be valid in Ireland, but this assumption has not been critically examined.

Statistical reliability of soil analyses

Since the analyses are not yet complete, it cannot be said at this stage that the estimates of BD, %C and depth are statistically reliable.

WORK TO BE DONE IN YEAR 2

1. Discussion with ITE to resolve problems raised by soil carbon work in NI in 1994-5. Check the comparability of soil analytical data with that for GB.

2. Obtain soil analysis data for all soil types in the remainder of the east. Calculate carbon density and total carbon store for 10 x 10 km squares.

3. Collect similar data for the west of NI. It is intended that the same method will be used as for the east, even though it has proved to be time consuming. In theory we might use the soil map database/coverage to find total areas of all soil types in 10 x 10 km squares, i.e. by intersecting it with a grid. This would follow the same procedure as used for land cover from the CORINE database (Part 1). It would allow all the soil map data to be used in estimating carbon - not only the domsoil, which can be a minority of a 1 x 1 km grid square. However, according to the method currently being used, one would then need domveg for the same part(s) of the 10 x 10 km grid square as each of the soils. In theory that could be found by simplifying the CORINE coverage into 5 domveg classes in ARC/INFO. The soil map coverage could then be intersected with the simplified CORINE coverage. Intersecting two detailed map databases is known to be a lengthy procedure and to involve data volume problems with the version of ARC/INFO now available in QUB. That method would also mean a greater difference in methodology between NI and GB. For these reasons it is rejected; it is suggested that the same methods be used for the west as for the east.

4. Create a soil carbon database (gridref, mean carbon density/ha and total carbon for 10 x 10 km squares).
Put the carbon density (tonnes/ha) into the same classes as will be used in GB. Produce a 10 x 10 km grid square map of NI.
Estimate the total amount of carbon (tonnes) stored in soils in NI as the sum of all 10 x 10 km totals.

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