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Estimates of carbon stores in four Northern Irish lowland raised bogs

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Soils store more carbon (C) than does vegetation and in Northern Ireland peat has been estimated to account for about 42% of the soil C store. This estimate, however, was based on incomplete field evidence, including uncertainty on peat depths and peat bulk density. This paper aims to show how the estimate might be improved, taking into account bulk density and carbon density measurement. Trial 3-D models are presented to estimate total C content of individual bogs. Results suggest that C stores in northern Irish lowland raised bogs are lower than previously estimated primarily because of low bulk densities which showed no consistent increase with peat depth. Bulk density varied within and between bog profiles on the same bog and between bogs leading to different estimates of C stores. The research indicates a need for more precise modelling of bogs based on stratigraphy and dating of layers and a need for standardised measurement of peat bulk density and carbon storage. The findings, particularly if they apply to the extensive blanket bog, affect local and national totals of soil C stores and have implications for national policies on increasing/preserving C stores.

Key words: peat bulk density, peat carbon density, peat carbon stores

INTRODUCTION

Compared with many other areas on the Atlantic margins of Europe, Irish peatlands are notable for their remaining extent, especially of that which is intact (that is not eroded, cut nor drained) and relatively undisturbed. Large areas of peatland have survived despite their value as a fuel and horticultural resource, which has in the past led to widespread peat harvesting, and their importance in forest planting. In Northern Ireland, the estimated extent of peatland varies depending on the purpose and methods of land classification. For example, Cruickshank and Tomlinson (1990) recorded peatland from air photo-interpretation, whereas in calculating soil carbon stores for Northern Ireland, Cruickshank et al. (1998) used data supplied by the Northern Ireland Soil Survey who used depth of the surface organic layer to define peat areas. Broadly, however, blanket peatland accounts for approximately 85% of peatland and lowland basin and raised bogs for 15%.

Governments which signed the Framework Convention on Climatic Change at the Earth Summit in Rio de Janeiro (1992) and have taken part in subsequent meetings, for example at Kyoto (1997) and Buenos Aires (1998), are seeking to limit the concentrations of greenhouse gases in the atmosphere and thereby to restrict the anthropogenic contribution to global warming. CO_2 is the main anthropogenous greenhouse gas and its concentration in the atmosphere can be limited by reducing emissions and/or by increasing that sequestered from the atmosphere and stored in vegetation and soils. Soils store more C than does vegetation; for example, in Northern Ireland the soil C store has been estimated as 386 Mt compared with a vegetation store of 4.4 Mt (Cruickshank et al. 1998). The estimate for the peat vegetation C store was approximately 0.26 Mt whereas that for the peat itself was 164 Mt. This estimate was based on several assumptions and incomplete field evidence as follows:

The area of peat in Northern Ireland was that mapped by the Soil Survey of Northern Ireland (Cruickshank 1997), whereby organic accumulation greater than 50 cm was classed as peat. Cruickshank et al. (1998) therefore used 1m as the minimum depth of peat because they were working in units of 50 cm. The Soil Survey did not record peat depth so that Cruickshank et al.(1998) calculated the mean peat depth for individual areas of bog from post-graduate theses, (Double 1954; Goddard, A. 1971; Goddard, I. 1971; Francis 1987) from the Northern Ireland Peatland Survey (Cruickshank et al. 1993) and surveys on peat extraction (Cruickshank et al. 1995). Whereas detailed depth measurements are unlikely to be made for the whole of the peatland area of Northern Ireland (15% of the land area as mapped by the Soil Survey), data on depth and extent have become available following a recent survey and profiling of peat bogs of major conservation interest (including both lowland raised bogs and blanket bogs (Grant et al. 1997; Tomlinson et al. 1998)).

In addition to information on depth, estimates of C stores require data on the carbon concentration (%C) of the peats and their bulk densities. For Northern Ireland, Cruickshank et al. (1998) had access to limited information on these variables and had to use that available from Great Britain (Milne and Brown 1997). This was adapted for the deeper peats found in Northern Ireland. It was assumed by Milne and Brown (1997) that carbon density (Mg C ha^{-1}) increased progressively with depth; variations depending on peat stratigraphy and the history of deposition were not considered. Subsequently, several of the major lowland raised bogs, which were part of the survey and profiling project (Grant et al. 1997; Tomlinson et al. 1998), have been cored and %C and bulk density measured at 10 cm intervals.

This paper brings together the recent studies on bog-profiling (Grant et al. 1997; Tomlinson et al. 1998) with ongoing work on C and bulk density, and aims to provide better estimates for the amount of C stored in a number of the major lowland raised bogs. It reviews the methods used to measure %C and bulk density, compares the new estimates with earlier ones and shows how geographical information system (GIS) modelling techniques can be applied to produce estimates of C stores in individual bogs.

METHODS

Ground-based survey of surface topography of peat bogs

During an initial visit to each peat bog the extent of the study area was determined by reference to 1:10 000 scale Ordnance Survey (OS) maps, used in conjunction with boundary maps supplied by the commissioning authority, the Environment and Heritage Service, Department of the Environment for Northern Ireland. The sites were all Areas of Special Scientific Interest [ASSI] or National Nature Reserves [NNR] delineated by the Environment and Heritage Service. A grid of survey points was established across the entire area of each site spaced 100–200 m apart depending on the size of the study area and the time available. The location and elevation of these points was then surveyed using an infra-red based electronic distance measurement system (Leica TC1010 total station), fitted with a data-logger (Wild GPC1) to record survey data automatically. Distances were measured in millimetres and angles in degrees, minutes and seconds. Where time and conditions permitted, the mid-way position between transect points was recorded to increase the resolution of the surface survey (down to 50 m intervals). Return visits to re-survey individual points, showed that the locational measurement for points varied by approximately 50 cm, whilst elevational readings had a lower level of discrepancy (up to 20 cm). In addition to the transect points, observations were made to several land-marks and reference points (such as road junctions and Ordnance Survey (OS) benchmarks). This enabled the survey data to be geographically-referenced against OS maps, and the elevation of survey points above an Ordnance Datum (mean sea level in Belfast Harbour) to be calculated.

Treatment and plotting of survey data

Field survey data were downloaded from the data-logger into Leica's Liscad data manipulation and plotting software. Peat depth data for each of the surveyed sample points were added to this point attribute file, and the elevation of basal surfaces above mean sea level was calculated. These data were then utilised to generate three-dimensional models of bog surface terrain and basin morphology using standard digital terrain model procedures. Peat depth was measured at each of the marked transect points using a light-weight gouge auger. The peat body was cored until the peat/clay interface was reached. Occasionally, despite repeated attempts, the full peat sequence could not be sampled owing to obstruction by wood or dense basal deposits.

The location and height data for the surface position and basal position of each survey point were joined in ARC/INFO and a new item created for peat height (depth) which was used to create a 3-D model (digital terrain model or DTM) from which the area of peat at 50 cm depth intervals was calculated.

Bulk density and carbon content

Cores for bulk density and C determination were obtained using a Russian peat corer with a chamber of 0.5 m length and 5 cm diameter. Each section of the core was divided into 10 cm samples and placed in ziplock polythene bags in the field. The samples were stored in a refrigerator prior to analysis. Air was evacuated from the bag using a suction pump, taking care to halt evacuation as soon as air in the bag was removed, and wet mass and volume measured; volume was obtained as the amount of water displaced upon immersion of the sample (Clymo 1983). Three sub-sample replicates were taken from each sample (leaving enough material for further work on *Sphagnum* identification) and dry mass measured after 24 hours at 105 ˚C. The dry replicates were ignited at 450 ˚C for 8 hours, weighed and loss on ignition calculated. Schulte and Hopkins (1996) found that these drying and ignition temperatures and times gave results for percentage organic C which, in mineral soils, correlated well with the chromic acid titration method of Walkley and Black (1934). Bulk density was calculated as grams dry mass per cm^3 wet volume. Carbon density (Mg ha^{-1}) was measured by multiplying the bulk density of peat by the depth and % carbon (%C), where %C was the loss on ignition divided by the van Bemmelen factor for peats, 1.92 (Allen 1989). Estimates of C content expressed as carbon concentration (%C) are unreliable because the amount of C present within a soil depends also on the bulk density and depth. An increase in bulk density with depth may cancel the effect of lower carbon concentrations (Davidson and Ackerman 1993).

Site Description

The recent survey and profiling project on Northern Ireland peat bogs (Grant et al. 1997, Tomlinson et al. 1998) included some of the largest lowland raised bogs. The bogs had relatively extensive areas of intact peatland. Bogs selected for the study of C stores encompassed a range from west to east and some which had active cutting on their margins. A transect was established from a cut face at Dead Island to be used for investigations into possible anthropogenic effects on C stores.

Moneygal Bog (54°45´N, 7°37´W) is the most westerly of those investigated to date (Fig. 1). Double (1954) described the bog as occupying a wide hollow between east-west trending hills. Cruickshank and Tomlinson (1988) and O'Connell (1987) described it as an intact raised bog within a wider blanket peat area. The survey and profiling (Grant et al. 1997) suggests, however, that its domed appearance may result from the underlying topography. Whereas therefore, the bog is to some extent lowland, basin peat within a blanket area, it may not be a true raised bog. The site totals 122 ha of which 48 ha comprise a central area of intact bog, including shallow pools, and an old bog-burst. Extensive cut-over peat surrounds the site and there are a few faces of active hand-cutting. Two cores were taken from this site,

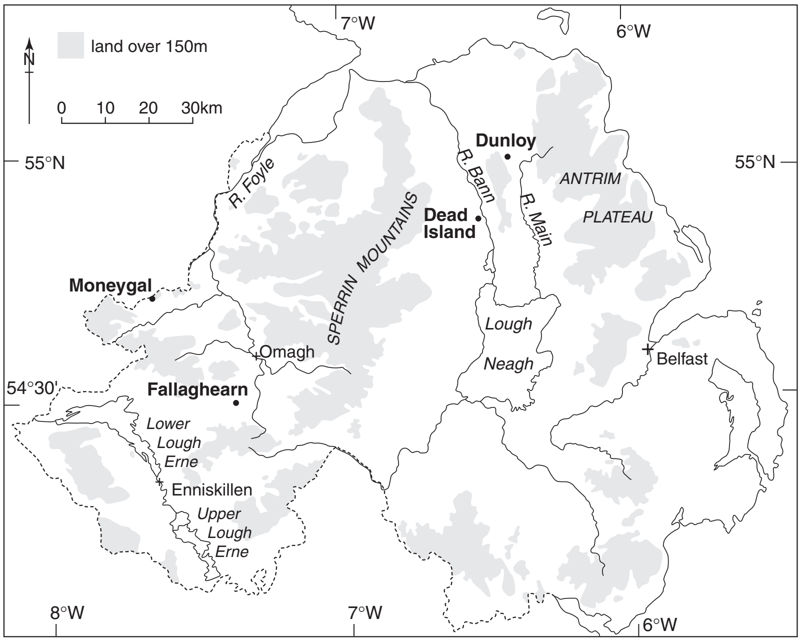

Fig. 1. Location of lowland raised bogs studied: Moneygal Bog, Fallaghearn Bog, Dead Island Bog, Dunloy Bog.

one at 10 m from the edge of the intact area and the other 20 m towards the centre.

Fallaghearn Bog (54°31´N, 7°20´W), in the centre-west of Northern Ireland, covers 50 ha and although it has a poorly defined dome, the majority of the present bog surface is intact. Hummocks and hollows are occasional and pools generally absent. Past cutting is evident around the margins along with some old drains. Occasional burning has taken place. Profiling of the bog (Grant et al. 1997) shows it to be over an uneven basal surface with basins at its western and eastern ends. Three cores were obtained from the centre of the eastern bog.

Dead Island Bog (54°53´N, 6°33´W) is located in the valley of the Lower Bann in the east of Northern Ireland. It comprises 55 ha within which is a central intact dome with well-developed hummocks and hollows and occasional pools. Cutting is extensive, especially in the south where it remains active. The profiling of the bog shows that it too has an uneven basal surface with the deepest peats overlying basins in the central/northwestern quarter of the bog. A series of 5 cores was taken at this site, stretching from a cut peat face towards the centre of the dome at 10 m intervals.

Dunloy Bog (55°00´N, 6°25´W), in the valley of the river Main, is one of the largest of the remaining lowland raised bogs (108 ha) in Northern Ireland. It has an intact centre of 44 ha. Although old drainage ditches cut around it, there are areas of moderate hummock-hollow microtopography and it has the most extensive lagg of the remaining lowland bogs. There is evidence of past cutting, but little active, and occasional fires have been noted in the recent past. Only preliminary work has been done at Dunloy Bog; the one core obtained is incomplete. It is continuous to 380 cm but thereafter has several missing layers. Whereas it cannot be used for any estimates of C store in Dunloy Bog, it is still of value in general discussion of trends in bulk density and carbon density with increasing depth. Further cores are currently under analysis.

RESULTS

Bulk density

The average bulk density from 1680 subsamples is 0.069 g cm^{-3}, but there is variation between bogs for example the mean bulk density for Fallaghearn

Bog (0.056–0.058 g cm^{-3}) compared with Moneygal Bog (0.069–0.07 g cm^{-3}) (Table 1). Variation also occurs between cores on any one bog. Whereas the overall mean bulk densities for each core at Fallaghearn show little variation (Table 1), the peaks and troughs in the cores rarely coincide at the same depth (Fig. 2). However there is some coincidence; all show a decline in bulk density from the surface reaching low values at 100–120 cm. The variability in bulk density also appears less between 300 and 680 cm in all three profiles than either above or below these levels. The high peak in bulk density at the bottom of Fallaghearn 2 is where the peat extends into a humic clay.

At Dead Island the series of bulk density profiles (DI-1 to DI-5) from the cut edge inward (Figs. 3a, 3b) shows in all cases a decline in bulk density from the surface to about 50 cm, compared with a similar decline at Fallaghearn to approximately 110 cm. Overall mean bulk densities are higher than at Fallaghearn (DI-1 0.084 g cm^{-3}, DI-2 0.074 g cm^{-3}, DI-3 0.085 g cm^{-3}, DI-4 0.073 g cm^{-3}, DI-5 0.066 g cm^{-3}), but although DI-5 has the lowest mean there is no general decline with distance from the cut edge of the bog. Profiles DI-1 to DI-3 show more variability than DI-4 and DI-5, especially down to around 250 cm. With the exception of the bulk density value at 300 cm, profile DI-5 is the most consistent. High values are notable at the base of DI-1 where the sediment changes from peat to humic clay (Figs. 3a, 3b).

Percent carbon

As found in previous studies (Heal and Smith 1978, Allen 1989, Immirzi 1992) the %C was consistent. For all the cores the mean values were around 51.11% ± 0.2. Apart from occasional anomalous results, which may be due to weighing errors, the only major deviation from the average, is in the bottom of deeper cores where humic clays and clays were encountered. An example is at Fallaghearn 2 where %C drops from around 51% at 10.6 m to around 30% at 11.0 m.

Carbon densities

Table 2 shows the estimated carbon densities for the bogs studied down to a depth common to all the cores, for example at Dead Island-1 for a depth of 1 m the carbon density is estimated as 505 Mg C ha^{-1} whereas for 1.5 m of peat the carbon density is 702 Mg C ha^{-1}. As a result principally of the variation in bulk densities between layers in the cores, there is variability in the estimated carbon densities but, with the possible exception of

Table 1. Depth, sub-sample dry weight (SS Dw) (mean ± standard deviation), bulk density (Bd) (mean, standard deviation and data spread), percentage carbon (%C) and mean carbon density in each core taken from Dunloy (Dun), Moneygal (Mon), Fallaghearn (Fal) and Dead Island (DI) Bogs, Northern Ireland.

Core	Depth (cm)	SS Dw (g)			Bd (g cm^{-3})					%C (%Dw)			C density (Mg ha^{-1})
		mean	±	S.D.	mean	±	S.D.	min.	max.	mean	±	S.D.	
Dun-1	1085	2.73	±	2.54	0.069	±	0.076	0.028	0.349	45.37	±	0.816	3436.34
Mon-1	480	1.77	±	0.51	0.071	±	0.007	0.037	0.147	50.25	±	2.66	1775.28
Mon-2	530	1.46	±	0.49	0.069	±	0.006	0.033	0.099	50.82	±	0.63	1847.83
Fal-1	700	1.14	±	0.35	0.056	±	0.011	0.031	0.099	51.41	±	0.41	1998.48
Fal-2	1100	1.32	±	0.64	0.058	±	0.008	0.032	0.081	50.93	±	2.66	3264.53
Fal-3	1050	1.51	±	0.54	0.057	±	0.010	0.022	0.081	51.37	±	0.37	3051.84
DI-1	570	0.91	±	0.45	0.084	±	0.006	0.034	0.237	51.28	±	0.77	2442.45
DI-2	420	1.03	±	0.36	0.074	±	0.005	0.035	0.119	51.15	±	0.64	1599.74
DI-3	550	2.46	±	1.09	0.085	±	0.013	0.018	0.205	51.39	±	0.32	2401.29
DI-4	550	2.03	±	0.58	0.073	±	0.005	0.048	0.106	51.37	±	0.41	2057.91
DI-5	600	1.87	±	0.67	0.066	±	0.006	0.032	0.115	51.29	±	0.44	2017.64

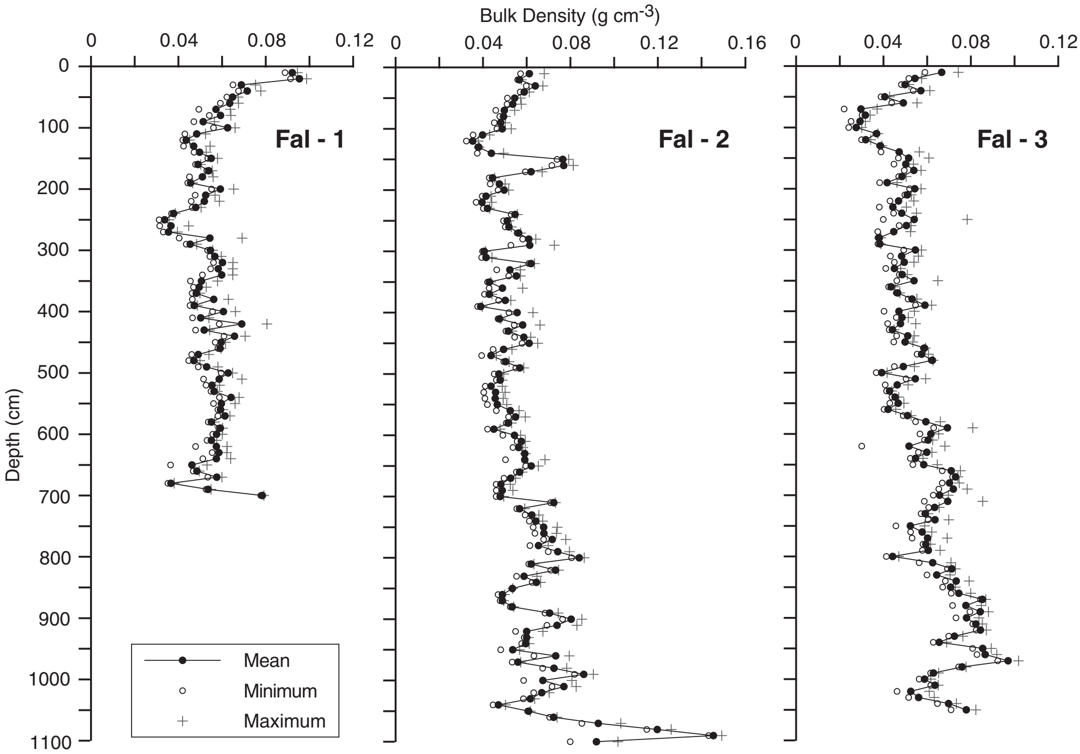

Fig. 2. Bulk density values for cores Fal-1, Fal-2, and Fal-3 at Fallaghearn Bog.

the top 1 m, the estimates are lower than those derived by Cruickshank et al. (1998). The average carbon densities shown in Table 2 mask the variability, but suggest that the over-estimate of carbon densities reported in 1998 increases with depth; for the top 1 m current estimates are around 5% lower than those of 1998, at 4.5 m they are 39% lower.

Estimates of the lowland peat carbon store and comparison with earlier estimates

The mean depth-related C densities (Mg ha^{-1}) from this study (Table 2, mean 1999) were multiplied by the area of lowland peat recorded (by 50 cm layers) in the Northern Ireland soil carbon database to give estimates of the C store in each 50 cm layer and in total (Table 3). It should be noted that the areas given in the soil carbon database are for 1 × 1 km grid cells and do not agree with the total area for lowland peat estimated in other studies as discussed above. Comparison of the C stores with those derived from the soil carbon database were made for only the upper 4.5 m; there were insufficient cores reaching greater depths to give reliable comparisons. The comparison (Table 3) shows that the C densities derived from the present study give a total C store which is 77% of that using data from the soil carbon database.

Estimates of carbon stores for individual bogs

Using the mean carbon density for 50 cm layers and the surface area for each layer, derived from the 3-D model of peat depth, the carbon store of each 50 cm layer of Fallaghearn Bog and the total store for the bog were calculated (Table 4). This was done for the two deep cores so that the effect of differing bulk densities, and thereby carbon densities, could be shown.

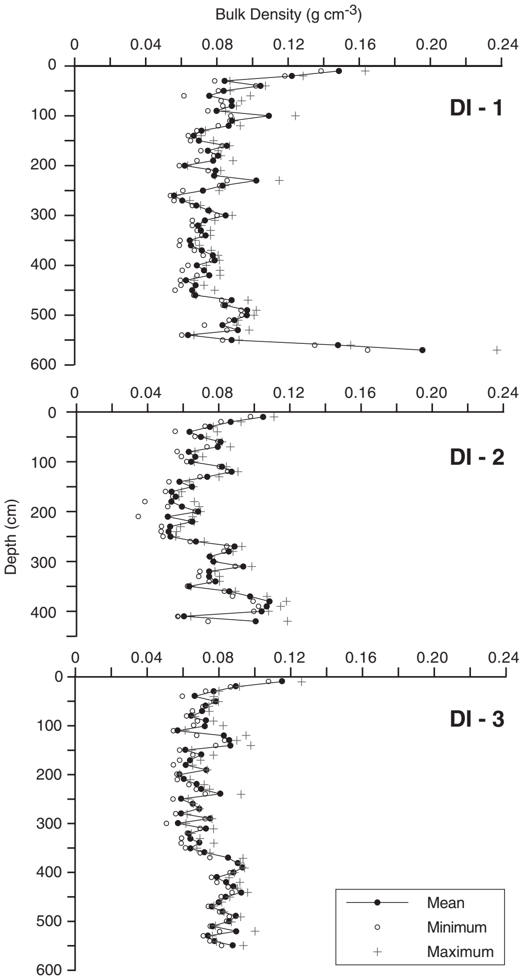

Fig. 3a. Bulk density values for cores DI-1, DI-2, and DI-3 at Dead Island Bog.

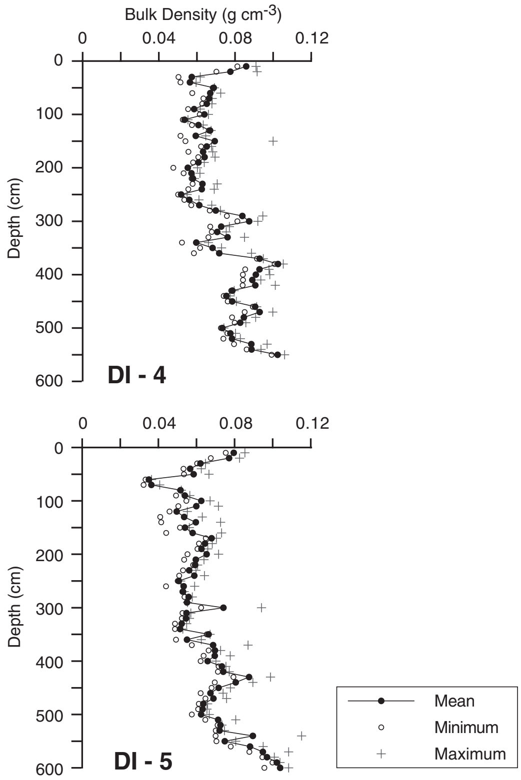

Fig. 3b. Bulk density values for cores DI-4 and DI-5 at Dead Island Bog.

Table 2. Comparison of carbon densities (Mg C ha^{-1}) between cores, bogs and with estimates from Cruickshank et al. (1998)

Depth (m)	Mon-1	Mon-2	DI-1	DI-2	DI-3	DI-4	DI-5	Dun	Fal-1	Fal-2	Fal-3	Mean 1999	Mean 1998	*%diff*
1.0	319	323	505	381	393	341	292	309	351	278	224	338	357	*-5.4*
1.5	499	443	702	570	664	500	434	427	477	398	330	495	607	*-18.5*
2.0	675	607	898	720	911	659	598	550	610	543	457	657	857	*-23.3*
2.5	843	750	1112	860	1176	809	744	685	725	660	583	813	1179	*-31.0*
3.0	1001	877	1290	1063	1380	992	894	800	841	799	699	967	1500	*-35.5*
3.5	1180	1069	1476	1260	1557	1181	1045	911	985	925	827	1129	1815	*-37.8*
4.0	1364	1249	1663	1518	1775	1414	1215	1027	1120	1047	955	1304	2124	*-38.6*
4.5	1570	1467	1840	1720	1992	1626	1414	1149	1272	1190	1079	1484	2442	*-39.3*

Table 3. Comparison of C stores in lowland peat in Northern Ireland using C densities derived in this study and those from Cruickshank et al. (1998).

Depth (m)	N.I. Soil Carbon database Area (ha)	Mean Carbon Density 1999 (Mg ha^{-1})	Carbon Store 1999 (Kt)	Mean Carbon Density 1998 (Mg ha^{-1})	Carbon Store 1998 (Kt)
1.0	24700	338	8348.6	357	8817.9
1.5	5500	495	2722.5	607	3338.5
2.0	6500	657	3613.5	857	4713.5
2.5	1200	813	975.6	1179	1414.8
3.0	1900	967	1837.3	1500	2850.0
3.5	700	1120	790.3	1851	1270.5
4.0	1500	1304	1956.0	2124	3186.0
4.5	1100	1484	1632.0	2442	2686.2
Total			21875.5		28277.4

Table 4. The area of each 50 cm layer at Fallaghearn Bog cores 2 and 3 and the carbon density for each layer and the total carbon store for Fallahgearn on the basis of each core.

Depth (cm)	Area (ha)	Fallaghearn-2		Fallaghearn-3	
		C density (Mg ha^{-1})	C store (Mg C)	C density (Mg ha^{-1})	C store (Mg C)
50	41.23	150.26	6194.9	138.12	5694.1
100	41.23	128.09	5280.9	86.11	3549.8
150	41.23	119.93	4944.5	105.44	4347.1
200	41.21	144.54	5956.1	127.39	5249.4
250	41.11	117.46	4828.9	125.70	5167.7
300	40.94	138.93	5688.0	116.26	4759.9
350	40.69	125.49	5106.5	127.96	5207.1
400	40.36	122.18	4931.8	128.01	5167.1
450	39.44	142.78	5631.8	124.14	4896.5
500	39.21	127.22	4988.8	137.22	5381.1
550	33.78	117.97	3985.5	121.30	4097.8
600	29.44	133.50	3930.9	145.97	4298.0
650	24.62	151.92	3740.6	146.96	3618.5
700	19.81	131.03	2596.9	181.50	3597.2
750	15.63	166.31	2599.7	158.42	2476.4
800	12.81	185.77	2380.3	145.17	1860.0
850	10.32	160.24	1653.6	176.34	1819.8
900	7.71	155.14	1196.7	205.65	1586.3
950	4.98	156.75	780.9	201.36	1003.2
1000	3.10	182.14	565.5	195.39	606.6
1050	1.73	159.32	274.9	163.87	282.8
1100	0.61	221.56	135.9		
1150	0.05				
Total		77393		74666	

DISCUSSION

Bulk density

The overall mean bulk density (0.069 g cm^{-3}) is lower than the 0.1 g cm^{-3} often quoted for peat (Immirzi et al. 1992). Milne and Brown (1997) in estimating the C content of peat in Great Britain used 0.09 g cm^{-3} for the bulk density of basin peat, which compares with the 0.091 g cm^{-3} reported for Finnish bogs (Mäkilä 1994 quoted in Clymo 1998). Several studies have shown an increase in bulk density with depth; for example Clymo (1978) found an increase in shallow *Sphagnum* lawn sites, although he has also pointed out that bulk density is not measured 'as commonly as might be hoped for scientific purposes' (Clymo 1983). Nor are the methods of estimation always clearly defined. Howard et al. (1994) assumed that bulk density increased with depth as a consequence of compression and Milne and Brown (1997) retained the ratio of bulk density at depth to that at the surface (from Howard et al. 1994) to estimate the bulk density of deep peat. Johnson and Durham (1963) showed variation in a valley bog at Moorhouse down to around 80 cm where the bulk density became more stable at approximately 0.054 g cm^{-3}. At 160–320 cm bulk density increased to 0.063 g cm^{-3}. In the Northern Ireland profiles there is no progressive, consistent increase in bulk density with depth which may explain the lower overall mean value and brings into question the assumptions of Howard et al. (1984) and of Milne and Brown (1997) as well as affecting C density estimates.

Throughout the profiles there are oscillations between layers with high and low bulk densities which may reflect changes in micro-topography from drier, possibly hummock conditions to wetter pools or *Sphagnum* lawns. The oscillations in bulk density may also be related to decay rate and length of time the plant material was exposed to aerobic decay (Jones and Gore 1978; Clymo 1978). The detailed stratigraphy of the cores remains to be examined. Some of these oscillations appear to be common across cores from a bog. At Fallaghearn there is coincidence of changes between 300 and 680 cm; for example, the high values at around 310–330 cm and 400–450 cm and the low values around 680 cm. At Dead Island, bulk density is high at around 300–310 cm and at 380 cm and low at around 500 cm. These coincident changes in the profiles of individual bogs may indicate localised factors affecting the bog as a whole but comparisons based on depth alone could lead to erroneous conclusions. Comparison of bulk density between cores should be based on detailed examination of the stratigraphy and on dating, but even then requires caution because of the variability within the 10 cm layers. In Figs. 2 and 3, the maximum and minimum bulk density for each 10 cm sample is shown in addition to the mean. Sampling at finer resolution than 10 cm might reduce the magnitude of the difference between maximum and minimum bulk density. This would have to be carefully considered given the availability of time and resources.

The use of displacement to measure volume (as described earlier) may result in diminished volume accuracy, but alternative methods also have problems. Using the volume of the corer was considered; however, due to the wetness of many of the cores, it was not always possible to ensure that the full core volume was achieved. In the absence of a standard method for obtaining volumes for wet peat samples, the current method was considered the least prone to error.

In general, bulk density is relatively high in the top 50–100 cm in all cores. This could be related to a change in *Sphagnum* species which has been noted to occur in many bogs in Britain and Ireland at around 1150AD (Barber et al. 1998); that is from a dominance of *S. imbricatum* to the present dominance of *S. magellanicum* and *S. papillosum*. However, such an explanation does not fit with bulk density profiles from Great Britain where there is no such increase towards the surface. The surface increase in bulk density may simply be another oscillation such as have occurred in the past and related to recent climatic and/or anthropogenic influences (such as cutting) and resulting vegetation change. There is no evidence that drainage activity in the surrounding area has caused an overall drop in the water table and thereby changing the structure of the surface peats.

The pronounced variability in the upper part of profiles DI-1 to DI-3 may be a response to cutting. The peat face near DI-1 is approximately 250 cm in depth and its influence on drainage and thereby on decay may stretch back to DI-3, although it might be expected that the variability would be more apparent at DI-1 than at DI-3. Examination of the surface revealed that micro-features were probably important in the variability of the bulk density values; thus cutting had produced tears in the peat surface near to DI-2 and DI-3 which may account for the variability in the upper part of those bulk density profiles.

Carbon density and carbon stores

The %C was found to be almost constant throughout the samples except for those from the bottom of deeper cores where peat merged into humic clays. Bulk density was therefore the dominant variable in carbon density estimates and because of the lack of a consistent, progressive increase with depth, there was a smaller increase in carbon density with depth than had been expected (Table 2). This resulted in a 23% lowering of the estimates of the C store of lowland peat bogs. The variability in bulk density and lack of consistent increase with depth also affect models of C accumulation in peat bogs (Clymo 1978, 1983; Gilmer et al. 2000). Such models initially have to be simple but may need to be refined to take account of variations in plant material, and thereby in bulk density, which the current study shows, are inherent in profiles.

3-D plots (DTMs = digital terrain models) of peat bogs can be sliced into a series of “layers”. This enables C stores of individual layers to be estimated. A simple trial example is presented here using 50 cm layers, but once stratigraphy has been completed, cores can be layered by dominant peat (vegetation) types and the C store for those layers calculated. This could give better estimates of C stores for individual bogs, but there remains the issue of whether sample cores are representative of the particular bog. As discussed above, varying micro-topography in the past results in different layers and depths of layers in cores from different parts of a bog. This is a similar problem to that encountered by pollen and tephra analysts who can obtain different results from cores taken on the same bog (Holmes 1998). It should also be borne in mind that DTMs are interpolations between survey points and will vary depending on the intensity of the survey points as well as on the software used to create them.

Cutting showed complex effects on bulk density (Figs. 3a and 3b) and the resulting carbon densities and stores, attributable in part to micro-features (e.g. tears) produced by the cutting. In view of the large proportion of peatland in Ireland that has been cut, these possible edge effects require further investigation. More widely, work is needed on bulk density, carbon density and stores of cut-over peatland which comprises nearly 78% of lowland peat in Northern Ireland. Although generally shallow, the extent of this cut-over peatland ensures that it is an important component of the total peatland C store. Research also needs to be expanded into blanket peatland which accounts for 85% of peatland in Northern Ireland although much of this has been cut-over (Cruickshank and Tomlinson 1990). If bulk densities in blanket peat also show a lack of consistent increase with depth, present estimates of soil C stores will be significantly reduced with implications for national C budgets.

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