The extent of recent peatland afforestation in Ireland

Kevin Black[a,b], Phillip O'Brien[c], John Redmond[d], Frank Barrett[d] and Mark Twomey[d]

Abstract

In 2004, the European Environmental Agency's (EEA) Spatial Analysis Group published findings from an analysis of CORINE data suggesting that 84% of the area afforested between 1990 and 2000 was on peat soils. The negative implications of these widely publicised statistics have been raised by environmentalists and policy makers alike. Our analysis shows that CORINE-based estimates of land use change are biased towards larger sized land parcels. Considering that more than 63% of land parcels afforested, in Ireland, since 1990 are less than 25 ha in size, the CORINE methodology tends to under represent the majority of afforested land parcels. In addition, comparison with high resolution Irish land cover and forest area geo data suggest that ca. 30% of the peatland area in the CORINE 2000 classification was misclassified. Work carried out by the Forest Service using the best available high-resolution data, estimated that the afforested area on peatlands is much lower than estimated by the EEA, representing 43.5% of total afforestation between 1990 and 2000. These results have been recently confirmed following the completion of the national forest inventory (NFI 2007a). This field-based assessment, which comprised 1,742 permanent sample plots, suggests that the percentage of peat afforestation between 1990 and 2000 ranged from 46 to 51% of the total afforested area.

Keywords

CORINE, peatland afforestation, national forest inventory

Introduction

Peatlands originally covered more than 17% or ca. 1,200,000 ha of the land surface of the Republic of Ireland. However, human use and modification over many decades, including private and commercial peat harvesting, afforestation and reclamation for agriculture following Ireland's entry to the European Community, have led to a significant loss of peatland cover.

In 2004, the European Environmental Agency's (EEA) Spatial Analysis Group published findings from an analysis of CORINE data suggesting that the 84% of the area afforested in Ireland, between 1990 and 2000, was on peat soils (EEA 2004). The publication of these findings in the national press raised public concern, and indeed criticism, about the extent of peatland afforestation and the loss of habitats.

[a] Corresponding author, FERS Ltd, 117 East Courtyard, Tullyvale, Cabinteely, Dublin 18, Ireland (kevin.black@ucd.ie).

[b] School of Biology and Environmental Science, University College Dublin, Belfield, Dublin 4, Ireland.

[c] Environmental Research Centre, Environmental Protection Agency, Richview, Clonskeagh, Dublin 4, Ireland.

[d] Forest Service, Department of Agriculture, Fisheries and Food, Johnstown Castle Estate, Co Wexford, Ireland.

The area of peatland afforested will also have important consequences on the net national uptake or emission of greenhouse gasses by forests under Article 3.3 of the Kyoto agreement (see Black et al. in press).

In this paper we consider the validity of the EEA analysis in a national context. We have given special consideration to the limitations of the CORINE methodology for the purpose of land use change and forestry detection within the fragmented land use landscape that exists in Ireland. In addition, a comparison is made between the published EEA data and high resolution GIS data sources, and results from the recently completed national forest inventory (NFI 2007a, b).

Background

Description of CORINE

Coordination of Information on the Environment, CORINE, is an EU initiative established in 1985. The CORINE methodology for indicating Change in Land Cover (CLC) between 1990 and 2000 is complex (CEC 1993). Computer aided visual interpretation of satellite images (Büttner et al. 2004, Steenmans and Perdigao 2001) was applied in the process of updating the 1990 European Land Cover to 2000 (±1 year) and the Land Cover change detection for the interval of 1990–2000, using Landsat MSS and TM satellite images. The smallest unit identified in CLC 2000 is 25 ha, and the minimum width of a linear feature is 100 m. Changes detected in the CORINE CLC 1990-2000 were incorporated in CORINE 2000 only if the final CORINE 2000 polygon met the minimum mapping unit criterion of 25 ha. This means that a newly afforested area can only be detected by CORINE if it is larger than 25 ha. Clearly this is unlikely to accurately represent private afforestation since 1990, because the average size of newly established private forest parcels is 8 ha, and they are highly disperse and fragmented.

The CLC2000 nomenclature includes 44 land cover classes covering agriculture as well as urban and natural land use. The forest definition used by CORINE Land Cover (Bossard et al. 2000) is: "Areas occupied by forest and woodlands with a vegetation pattern composed of native or exotic coniferous and/or deciduous trees and which can be used for the production of timber or other forest products. The forest trees are under normal climatic conditions higher than 5 m with a canopy closure of 30% at least". Codes 311 representing deciduous forests, 312 for coniferous forests and 313 for mixed forests were used to interpret the change in forest area. An additional class, CLC324, was included in the analysis, based on the assumption that this would represent recently felled and afforested areas, which are less than 10 years old. However, CLC324 areas also include some semi-natural woodlands and scrub colonisation of cutaway peatland. This reclassification of land areas without ground truthing is one of our main concerns with the CLC 1990 to 2000 analysis.

High resolution Irish datasets

A number of data sources were used to derive land use change statistics to examine the extent of the Irish afforestation programme on peat soils. Two GIS overlay

techniques were used to generate an afforested area-soils matrix between 1990 and 2000, namely point sampling and polygon intersection using Arc-GIS 9.1.

The afforestation grant and premiums dataset (iFORIS)

The afforestation grant and premiums scheme was introduced under European Commission Council Regulation 2080/92 to support afforestation of agricultural land as part of accompanying measures to CAP reform. The afforestation grant and premiums dataset captures all areas afforested following successful grant application. All afforestation areas recorded by the Forest Service are verified using a strict control and referrals process, which can include a post establishment site visit by a forestry inspector (Forest Service 2003). These datasets were primarily digitised using the 1:10650 and 1:2500 Ordnance Survey Ireland (OSi) raster maps. Post 2000 afforestation has been captured using 2000/2004 digital ortho-photography also produced by the OSi. The digitised grant and premiums afforestation database (iFORIS) represents 78% of the officially reported area for the period 1990 to 2000. These data sources are being updated for the new Forest Service Corporate system used to administer grant aided afforestation schemes (iFORIS).

Coillte afforestation dataset

This dataset was generated by Coillte, the Irish Forestry Board, and represents 100% geo data coverage for areas afforested over the reference period 1990 to 2000. This dataset was digitised using the OSi 1:10560 raster. The combined Coillte and iFORIS datasets represent a 96% spatial coverage of the area afforested between 1990 and 2000 (162,724 ha).

Irish Forest Soils (IFS) & land cover datasets

The soils and land cover datasets were derived from a number of map sources, remote sensed and ground-truthed data. These form part of a suite of maps provided to the Environmental Protection Agency (EPA) by the Spatial Analysis Group, Teagasc (Fealy et al. 2006).

A land cover map with a minimum resolution of 1 ha was derived using aerial photography and satellite imagery (Fealy et al. 2006). The land cover mapping exercise used the known occurrence of grassland types in Ireland in relation to soils. Thematic classes include grassland, bog and heath, rocky complexes, bare rock, forest (unenclosed) & scrub, urban land, coastal complexes, and water bodies (Fealy et al. 2006). The land cover dataset was derived primarily from remotely sensed data, including 1995 Landsat TM satellite imagery, 1995 black & white stereo aerial photography, and 2001 ETM satellite imagery.

The digital soil mapping project delivered soil and subsoil/parent material maps by extending information obtained from various surveys using a soil cover model (see Fealy et al. 2006). Over 40% of the dataset is a direct derivative of the National Soil Survey (Gardiner and Radford 1980) and has a minimum mapping unit of 1 ha. Subsequently, the FIPS-IFS project produced a first-approximation soil classification for those areas not previously surveyed by the National Soil Survey (NSS), using a

methodology based on remote sensing and GIS. A modelling approach was then adopted to produce a projected map for Ireland using a modular system based on different soil/peat forming factors, such as sub-soils, parent material, vegetation and topography (see Fealy et al. 2006 and Loftus et al. 2002). These maps were then combined to create a predictive model of soil/peat occurrence, which is represented in GIS map form.

The OSi county boundaries and colour air photos

The OSi boundaries were extracted from the OSi Discovery Series, while the colour air photos were taken in 2000, at a scale of 1:40000. The latter was primarily used for visual checks of all other datasets.

The National Forest Inventory (NFI)

The Forest Service published results from the NFI in 2007. It was based on a randomised systematic grid sample design, at a grid density of 2 x 2 km, to provide the number of plots needed to estimate total standing volume with a precision of ±5%, at the 95% confidence level. The grid generated 17,423 intersections, each representing 400 ha. Land use was classified at each intersection, including afforested areas, using photo-interpretation of OSi aerial photographs, aided by supplementary information such as the Coillte and the iFORIS datasets. This resulted in the classification of 1,742 points as forest land. At each point permanent sample plots, representing 500 m^2, were set up. At each plot a wide range of growth, carbon stock, forest type, soil and other variables were assessed and electronically stored. Data collection began in November 2004 and was completed in November 2006. Quality control was implemented by carrying out an independent subsample of the plots, and by inbuilt checks in the data collection software.

A series of permanent plots were selected to represent the post-1990 afforested area using the iFORIS dataset, aerial photographs and ground measurements of tree age, and assessment of forest development phase (afforestation, first or second rotation).

The soil group classification used in the NFI was a modification of the great soil groups used in the National Soil Survey (Gardiner and Radford 1980), with the addition of sand, making 11 great soil groups: brown earth, gley, regosol, grey brown podzolic, rendzina, sand, brown podzolic, basin peat, lithosol, podzol and blanket peat. Soils had to have a peat depth greater than 30 cm in the drained state, and 45 cm in the undrained state. Basin peat consists of fen peat and raised bog and occurs almost entirely in low lying areas in the Midlands. Blanket peat occurs in high rainfall areas, down to sea level in the western half of the country, and at high elevations elsewhere. It is characterised by acid-loving plant species, such as *Sphagnum*, *Calluna*, *Tricophorum* and *Eriophorum*. Basin and blanket peats were further subdivided into cutaway peat and flushed or unflushed peats.

Analysis and comparison of land use change and soil matrices

Using the national high resolution datasets a number of analyses were carried out, independent of the CORINE analysis, to generate estimates of afforestation on peatland from 1990. The breakdown of the analysis is now described.

Comparison of land parcel resolution of different datasets

The frequency of post 1990 forest land parcel size, derived from the high resolution national forest geo datasets (Coillte and iFORIS), was compared with data derived from the national CLC 1990 and CLC 2000 to test the spatial accuracy of CORINE land use classification. For this analysis, the national forest estate geo data were processed using GIS to dissolve internal sub-compartment boundaries and adjoining forest compartment areas; so that the land parcel size could be compared to the CORINE data (CORINE and satellite data cannot distinguish internal boundaries within forest land parcels).

As the composite national forest estate dataset represented both a high resolution and spatially accurate representation of the estate, it was decided to intersect these with the CORINE 2000 dataset to test how spatially accurate CORINE was at mapping forests and other land uses.

Analysis of Forest Service and Teagasc soil datasets to generate independent estimates of afforestation of peatland

Forest Service datasets including forest, soils, OSi boundaries and ortho-photos were used to estimate afforestation of peatland over the 1990s reference period, to compare with the EEA study, and into 2006 to show more recent trends in relation to peatland afforestation.

The Teagasc Land Cover dataset intersected with CORINE data to compare peatland mapping

In this analysis the Teagasc (IFS) Land Cover polygons were intersected with the peatland polygons from CORINE 1990 and 2000 to compare peatland mapping.

The NFI dataset

Soils data from the NFI were initially analysed to estimate the distribution of soil types across the entire forest estate. To provide comparison with the EEA data, a subset of NFI data, representing land afforested between 1990 and 2000 was extracted based on mean stand age and planting year.

An additional analysis using a subsample of NFI and iFORIS data representing afforested areas from 1999 to 2005 was performed to demonstrate recent trends.

Results

CORINE land misclassification and resolution

Some 37% or 240,422 ha of the land area classified as forest by CORINE 2000 is misclassified when compared to the national forest geo data (Coillte and iFORIS data). This is a consequence of the conglomeration process within the CORINE

methodology, which tends to underestimate smaller land cover parcels within a heterogeneous landscape. Therefore, pockets of peatland, grassland and other land cover areas can exist within a polygon which is dominated by forest. Likewise, pockets of forest within a landscape dominated by another land cover will be underestimated. The CORINE methodology assumes zero bias in the overall allocation of land use at the national level.

The CORINE digitising process may also result in overestimation, generalisation or amalgamation of land cover types. For example, when the residual parts of polygons are added to the neighbouring polygons during the CLC amalgamation process, the resulting shape and area changes are not the consequence of human impact or natural developments, but the result of amalgamation.

Significant discrepancies exist between CORINE and the Teagasc IFS-land cover data. Table 1 shows the results of the analysis of intersecting the Teagasc IFS-land cover dataset with the peatland classification from CORINE 2000. It is evident that the two datasets spatially coincided for 796,386 ha, representing a peatland area match of 69.5% for the dataset overlay (rows 1 to 6). However, 349,789 ha or 30.5% of what CORINE 2000 classified as peatland was classified as another land cover according to the IFS land cover dataset. Most of these IFS non-peatland land cover polygons, which intersected with CORINE peatland polygons were classified as grasslands (17.3%, Table 1, rows 7 and 8) and rocky complexes (6.7%).

Table 1: Intersection of CORINE 2000 peatland cover with the IFS land cover data.

IFS grid code	*IFS land cover classification*	*Area (ha)*	*%*
1	Bare soil	434	<0.1
2	Bog & heath	608,798	53.1
3	Bog	29,959	2.6
4	Cut bog	59,232	5.2
5	Cut & eroding bog	91,553	8.0
6	Bare peat & soil	6,410	0.6
IFS peatland cover intersected with CORINE peatland		796,386	69.5
7	Wet grassland	111,184	9.7
8	Dry grassland	87,264	7.6
9	Water	5,700	0.5
10	Unclassified	89	<0.1
11	Bare rock	6,569	0.6
12	Rocky complex	76,503	6.7
13	Mature forest	9,396	0.8
14	Forest & scrub	19,315	1.7
15	Built land	18,982	1.7
16	Sand	28	<0.1
17	Coastal complex	252	<0.1
18	Unclassified	14,507	1.3
	Other IFS land cover intersecting with CORINE peatland	349,789	30.5
	Total IFS/CORINE peatland intersected area	1,146,175	100.0

The CORINE misclassification issue seems to be related to two factors: dataset resolution and land use definition. The 25 ha minimum resolution of CORINE is too coarse to accurately delineate forest boundaries due to the fragmented nature and small size (average 5.8 ha, median 3.1 ha) of Irish forest compartments.

For a more valid comparison with CORINE, adjoining forest compartment boundaries were dissolved to arrive at larger areas. Following data processing (using the dissolving tool in Arc GIS) the average and median size of afforested areas were 18 and 14.3 ha, respectively. The frequency distribution of these land unit areas converted to forestry since 1990, based on high resolution datasets, shows that some 63% of the afforested dissolved boundary areas are less than 25 ha (80% of afforested area, Figure 1A). Thirty seven percent of afforested land parcels are larger than 25 ha, but only account for ca. 20% of total afforested area. Subsequent GIS analysis, based on an intersection of the afforestation land parcels > 25 ha and the IFS soils data, suggests that a high proportion of these large afforested areas are on peat soils.

Figure 1 also shows the frequency distribution of CORINE CLC forestry areas as a function of polygon size. The CORINE sample population histogram plot shows a distinct bimodal distribution of land use change area, with the split in the distribution occurring at 25 ha, the lower detection limit of CORINE.

The left hand side of the distribution represents isolated CORINE afforested land polygons between 5 ha and 25 ha (up to the arrow in Figure 1B). These polygons were all initially >25 ha, but were decreased in size due to the CORINE 1990/2000 intersection (i.e. the creation of smaller 'sliver polygons'). The right hand side of the distribution represents forests areas >25 ha, including smaller 'sliver polygons' now merged as one afforested land parcel.

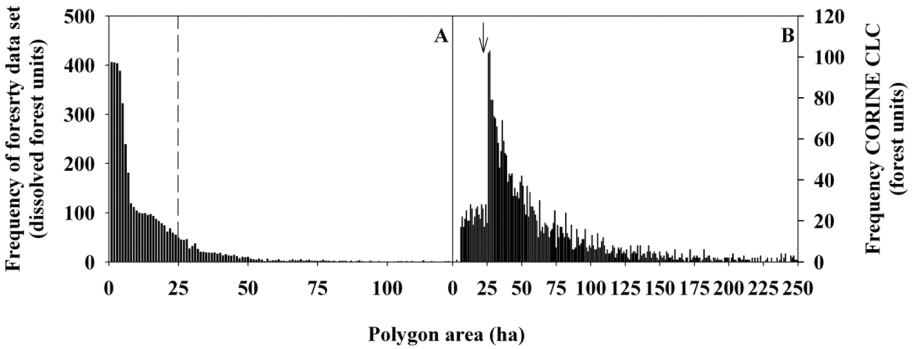

Figure 1: Frequency distributions of the forest land parcel size as derived from the national forest estate geo data (A) and CORINE 1990 and 2000 data (B). The dotted and broken lines in Figure 1A indicate the resolution of CLC 1990-2000. The arrow in Figure 1B indicates a distinct change in the detection frequency of the land use change (5 to 25 ha).

Comparison of different data sources

Both the NFI results and the analysis performed to intersect the IFS soils dataset with a composite national forest estate dataset show a considerably lower afforestation rate on peatlands, when compared to CORINE CLC analysis (Table 2). For the IFS soils and forest intersect, afforestation attributes for the 1990 and 2000 period, national forest estate datasets were generated and used in the intersection. From this available data, the total area of peat soils afforested was estimated to be 70,741 ha or 43.5% of the total area afforested in the reference period 1990 to 2000.

For the forest and IFS intersect analysis, blanket peat soils accounted for the largest proportion of peatlands planted with forests at 62.7%, followed by cutaway raised bog (32.3%), cutaway blanket peat (2.9%), intact raised peats (1.9%) and fen peat (insignificant).

Although the forest/IFS intersect area and officially reported afforested area is higher than the NFI estimated area (Table 2), this is due to the land use classification used in the NFI methodology, where open areas within forest boundaries are not counted as forest.

Table 2: A comparison of peatland area afforested (public and private) between 1990 and 2000 according to CORINE (EEA, 2004), the IFS soil/forest estate intersect and NFI datasets.

Dataset	*Peat area afforested ha*	*Estimated afforested area ha*	*%*
CORINE (EEA)	98,000a	116,667	83.9[a]
IFS soils/Forest	70,741	162,724	43.5
NFI[b]	72,979 (63,324 – 82,635)[c]	149,410 (136,320 – 162,500)[c]	48.8
Official total area 1990-2000		168,841	

[a] Taken from EEA (2004)

[b] The peat area afforested includes basin, blanket and cutaway peat. The estimated afforested area includes forest land only, open spaces such as ride lines and riparian zones are excluded. See NFI Methodology for definitions (NFI 2007b).

[c] NFI estimates exclude open areas within forest boundaries. Values in parenthesis show the confidence interval at $p \leq 0.05$.

Recent trends in peatland afforestation

Both the NFI and IFS-forest intersect estimates show a general decline in the afforestation of peatland from 1990 to 2006 (Figure 2A). The IFS-forest intersection estimates show a general downward trend in peatland afforestation, from 61.7% in 1990 to 32.9% in 2005. Similarly, the NFI data indicates a downward trend from 55% in 1990 to 43.1% in 2005. It should be noted that the total peatland area afforested since 1990 declined at a faster rate, when compared to proportional estimates, due to a decrease in the total area afforested in recent years. The spatial data estimates show that total peatland afforestation in 1990 was ca. 9,000 ha, compared to ca. 4,000 ha in 2005.

The proportional decline in peatland afforestation was consistent with a relative increase in afforestation on gley, grey brown podzolics and brown earths over the same period (Figure 2 B).

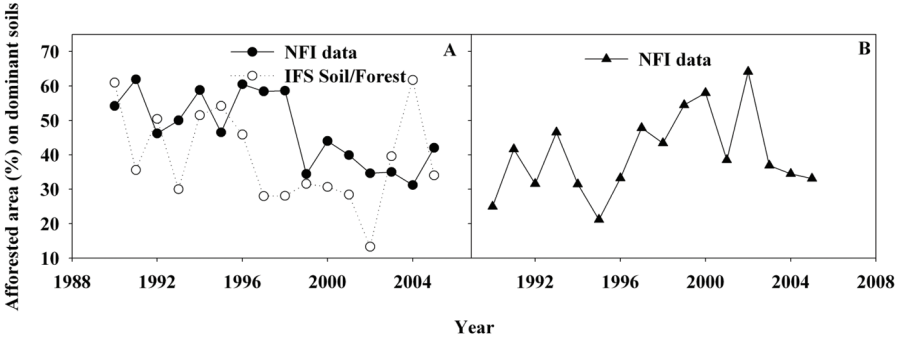

Figure 2: Afforestation of peatlands (circle symbols, A) and main mineral soil types (triangle symbols, B) from 1990 as determined the NFI and IFS soil/forest intersect estimates.

Statistics for the entire national forest estate

According to the NFI, 10% of the Irish landscape (697,840 ha) comprises forest and semi-natural woodlands. This includes open areas (72,100 ha) within forest boundaries, forest roads and ride lines. Forty-three percent of the total forest estate is located on peats. This includes plantations as well as semi-natural woodlands, such as the birch colonisation of cutaway peat. Gley soils are the other dominant soil group, occupying 26 % of the total forest estate (Table 3).

Table 3: Soil group composition of the national forest estate (from National Forest Inventory).

Soil group	*Area*	*Confidence interval (α=0.05)*		
		ha		*%*
basin peat	74,080	65,140	83,020	10.60
blanket peat	218,850	205,700	232,000	31.30
brown earth	58,880	49,900	67,870	8.40
brown podzolic	31,300	24,660	37,940	4.50
gley	181,280	167,740	194,830	26.00
grey brown podzolic	17,250	12,300	22,210	2.50
lithosol	16,410	11,520	21,290	2.40
podzol	74,120	64,680	83,560	10.60
regosol	6,430	3,300	9,570	0.90
rendzina	8,410	4,880	11,930	1.20
cutaway peat	8,840	5,190	12,480	1.30
sand	1,190	-	2,540	0.20
marl	400	-	1,200	0.06
limestone pavement	400	-	1,190	0.06
Total	697,840			100.00

[c] *Includes both forested areas and open areas which are integral to the forest (NFI 2007a).*

Discussion

Based on this comparative analysis, we have shown that the EEA CORINE-based estimation of afforestation of peatland was a large overestimate, when compared to independent high resolution geo data and ground-truthed NFI information. While there was good agreement between the NFI and IFS-forest dataset, it should be noted that these afforested estimates are based on afforestation and soil type statistics. In contrast, the CORINE afforestation estimate on peatlands is based on land cover classification statistics. However, the preliminary comparison of high resolution IFS land cover data and CORINE clearly show that there is a mismatch in land cover classification. Therefore, we suggest that the overestimation of the CORINE afforested area on peatlands between 1990 and 2000 in Ireland may be associated with:

1. statistical misrepresentation of Irish forest land parcels in CORINE (i.e. low resolution of CORINE) and
2. aggregation of classified categories, which may not reflect afforestation. This may be particularly relevant for CLC 234 (transitional woodland and scrub land), which may also include areas subjected to encroachment by hazel on the Burren, birch colonisation of cutaway midland peat and alder scrub on previously grazed upland.

CORINE classification and resolution problems have been highlighted in other comparative studies across northern Europe (Hazeu and de Wit 2004, Cruickshank and Tomlinson 1996). A study conducted in the Netherlands showed a 95% accuracy when CORINE 2000 areas were compared to orthophotography data on areas greater that 25 ha. However, when all areas, including land use parcels less than 25 ha, were compared, the accuracy decreased by 30% (Hazeu and de Wit 2004). A similar study conducted in Northern Ireland by Cruickshank and Tomlinson (1996), also highlights the resolution issue in relation to forest and woodland parcel size. More importantly, it was suggested that there was a bias towards Mediterranean land use in the CORINE classification, and there was a need for land classification subdivisions to avoid generalisations of peatland and pastures. These findings, together with the results presented here, suggest additional land classes for North-western Europe may be warrant inclusion in CORINE CLC. However, there is no indication that CORINE 2006 will include additional CLC nomenclature changes.

Temporal analysis of both the spatial geo data and NFI datasets suggests that there is a downward trend in peatland afforestation since 1990 (Figure 2). This not primarily related to a decrease in the afforestation rate since 1990, but rather a proportional increase (ca. 20%) in afforestation of mineral soils since 1990 (Figure 2B). These trends are likely to continue given the introduction of biodiversity enrichment incentives within afforestation grant and premium schemes, which favours the planting of broadleaved species on productive mineral soils, previously used for agriculture.

Finally, we suggest that afforestation, soil type and land-use change trend statistics should be taken from nationally derived high resolution data. The resolution and land class classification used for CORINE is clearly not representative of the

Irish landscape. The publication of these data has significantly overestimated the extent of peatland afforestation.

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