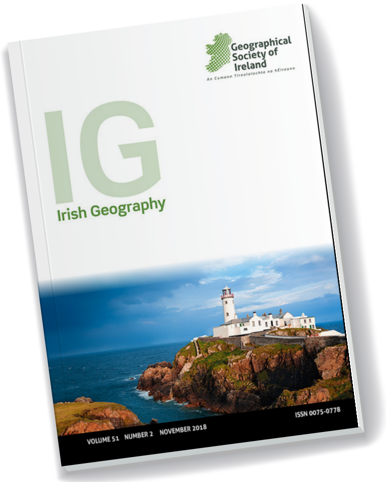

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Mapping land use on Irish peatlands using medium resolution satellite imagery

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Abstract: The EU is committed to quantifying greenhouse gas emissions and removals from land use, land use change and forestry, including wetlands. Wetlands and peatlands will play a central role in achieving temperature goals agreed in the Paris Agreement. Throughout Europe and particularly in Ireland, peatlands have been under severe strain for decades. Irish peatlands cover about 20.6% of the land and up to 85% are degraded. Medium resolution satellite data were analysed using a combination of object-based image assessment and peatland maps to produce land use maps for the 2005 to 2006 period. Four peatland land use types were detected: grassland, forestry, industrial peat production, and residual peat. Persistent cloud was an issue along the western seaboard and peatlands in these areas were excluded from the analysis. Despite this issue, the results show that 66% of peatlands have undergone land use change: 35% to grassland; 27% to forestry; and 4% to industrial. The overall map accuracy was 77%. The results could be used to aid the development of baseline data on peatland land use in Ireland for the 2005-2009 base period as required by the 2030 Climate and Energy Framework. The methodology may be used to quantify land use and land use change on peatlands across the EU.

Keywords: *peatlands, Earth observation, OBIA, land use mapping, land use change*

Introduction

The long-term goal of the Paris Agreement is to keep the global temperature increase well below 2 °C above pre-industrial levels and to pursue efforts to keep it to 1.5 °C above pre-industrial levels (UNFCCC, 2015). It incorporates a new goal that includes land use and forests with the aim of achieving '*a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century*' (UNFCCC, 2015). The agreement also invites '*Parties to take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases, including forests*' (European Commission, 2016). The EU's commitments to the Paris Agreement are outlined under EU Regulation 2018/841,

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wherein it states that greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF) are included in the 2030 climate and energy framework (European Parliament, 2018). Within this framework, forests, agricultural land and, importantly, wetlands will play a central role in achieving the temperature goals agreed in the Paris Agreement (European Parliament, 2018).

Wetlands in Europe have been under severe strain over the last 100 years. Many wetlands (including peatlands) have been degraded with others having undergone land use change. Habitats Directive reporting shows that only 13% of wetland habitats have favourable conservation status (European Commission, 2015). Degradation and Land use change impacts on natural capital and specifically on ecosystem services such as carbon sequestration and water regulation, particularly in peatlands (Chapman *et al.,* 2003; Freeman *et al.,* 2001; Holden, 2005; Limpens *et al.,* 2008; Moore and Knowles, 1989; Turetsky *et al.,* 2002). Throughout Europe, wetland natural capital has been degraded: Lithuania has lost 70% of its wetlands in the last 30 years; south-western Sweden has lost 67% in the last 50 years and in the UK, 84% of peat soils have been lost since the 1950s (European Commission, 2007). Much of the loss can be attributed to land use change with up to 68% of wetland habitats being afforested from 1990 to 2000 (European Commission, 2007). The loss and degradation of wetlands is undermining efforts to attain climate change objectives (EU, 2013) given their effectiveness at sequestering and storing carbon (European Parliament, 2018). Under the 2030 climate and energy framework, from 2021, member states must begin to report on carbon emissions and removals from managed wetlands. This reporting will be in relation to the base period of 2005 to 2009 (European Parliament, 2018).

In Ireland, the predominant wetland type is peatland. Peatland habitats cover about 20.6% of the national land area (Connolly and Holden, 2009). However, most of these habitats are in an unfavourable condition (National Parks and Wildlife Service [NPWS], 2013). In 2001, Foss *et al.* (2001) estimated that both raised bogs and blanket bogs had been severely degraded with only 8% and 21% (respectively) remaining ecologically intact. Ten years later, the Bogland report found that there are no more intact raised bog landscapes in Ireland and that the area of active blanket bogs, while unknown, is likely to have decreased (Renou-Wilson *et al.,* 2011). Under the EU Habitats Directive, the National Parks and Wildlife Service (NPWS) reports that all categories of Irish peatlands: Raised Bog (Active); Degraded Raised bogs; Blanket Bog (Active) and Transition Mires, achieved a 'bad' conservation assessment (NPWS, 2013). Recent studies estimate that peatland degradation is continuing with up to 85% of peatlands degraded to some extent (Connolly and Holden, 2011a, 2011b; EPA, 2016; Holden and Connolly, 2011; NPWS, 2013; O'Connell *et al.,* 2013; Wilson *et al.,* 2013). This degradation is due to the wide variety of land use and land use change that occurs on these peatlands (Renou-Wilson *et al.,* 2018).

Change in peatland land use is not a new phenomenon in Ireland. As early as 1685, bogs were regarded as unproductive land that should be converted to more productive uses (King, 1685). In the early 1800s, The Bog Commissioners (1810-1814) recommended that the vast bogs in the midlands of Ireland should be drained and converted to agricultural land to grow the raw materials needed by the British in their wars with Napoleon (Horner, 2005). Between 1814 and the 1940s, much of the degradation and land use change may have been related to draining the bogs to 'improve' the land for agricultural use (Carroll-Burke, 2002). Post 1940, Hammond (1979) notes that 'major investments were made to develop the peat fuel industry' which led to land use change for about 40,000ha of raised bogs in the Irish midlands. The State afforestation programme began in 1948 (DAFM, 2018) and between the 1950s and 1990 about 200,000ha of peatlands were afforested (Farrell and Boyle, 1990). This process accelerated between 1990 and 2000 with up to 98,000ha of peatland afforested (Black *et al.,* 2008). These land use changes meant that less than one third of the country's original area of peatland remained intact (Bullock *et al.,* 2012).

To report on the status and extent of peatlands, they must be mapped. Traditionally, peatlands were mapped using ground survey or an amalgamation of ancillary data, including older maps, e.g., Hammond's Peatland Map of Ireland; The Derived Irish Peat Map (DIPM); and DIPM version 2 (Connolly *et al.,* 2007; Connolly and Holden, 2009; Hammond, 1979). However, national scale mapping and monitoring of peatland habitats is a difficult and expensive task. Since 1990, land cover in Ireland has been mapped using CORINE (Co-ordinated Information on the Environment) (O'Sullivan, 1994). CORINE has been updated every six years since 2000. While CORINE is useful for examining changes in land cover over time, it does not examine land use within land cover classes such as peatland. Therefore, it does not offer the accuracy needed to respond effectively to environmental legislation (Heritage Council, 2017). O'Sullivan *et al.,* (2015) produced an indicative land use map for Ireland. They combined several datasets (Land Parcel Identification Service; Forest Service data and Natura 2000) within a GIS to establish the location and geographical extent of land use in combination with several drainage classes. However, they focused predominantly on agricultural areas and exclude grassland that occurs on peatland.

Earth observation (EO) is beginning to replace traditional mapping techniques (O'Connell *et al.,* 2014). EO, using a variety of techniques from Unmanned Aerial Vehicle (UAV) to satellite, enables large areas to be classified and mapped. Connolly *et al.,* (2011) used coarse spatial resolution (SR) imagery (SR = 250m) MODIS Enhanced Vegetation Index (EVI) data to detect and map land use changes on upland blanket bogs in the Wicklow Mountains. However, given the coarse spatial resolution of the MODIS imagery, only large scale change, such as fire or afforestation, was detected (Connolly *et al.,* 2011). The Irish Land Mapping Observatory (IMLO) was launched in 2012 to develop methods to detect land cover and land use specifically in agricultural lands (IMLO, 2018). A combination of radar, optical satellite data and the OSI's Prime2 database was used to detect land cover and use. Within the IMLO project, Barret *et al.* (2014) used radar data and machine learning algorithms to develop accurate inventories of grasslands. Medium resolution Landsat ETM+ imagery (SR = 30m) was used by Brown *et al.* (2007) to map blanket bog in Scotland. These data were useful for discriminating between peatland and non-peatland areas. However, the resolution was too coarse to distinguish between different peatland types.

In Ireland, medium resolution imagery has been used to map peatlands including: exposed and vegetated peatland areas (Cawkwell *et al.,* 2010); peatland land use (Connolly and Holden, 2011a) and to examine upland areas (Nitze *et al.,* 2014). O'Connell *et al.* (2014) used medium resolution imagery to develop an EO monitoring protocol to detect vegetation change on Irish peatlands. Medium resolution imagery was also used to create the CORINE 2012 land cover map (Lydon and Smith, 2014). Medium resolution is suitable to examine large scale land use changes in the landscape such as widespread afforestation (Shalaby and Tateishi, 2007). However, smaller scale evolutionary changes such as erosion, colonisation or degradation may be indistinct and require higher resolution imagery (Foody and Boyd, 1999; Shalaby and Tateishi, 2007). Although, EO offers opportunities to map land use and land use change, care needs to be taken in relation to peatlands as the land cover and land use may not indicate that a peatland or peat soil is present. In this work, medium resolution India Remote Sensing (IRS) imagery was used in combination with the DIPMv2 to overcome the land cover issues and deliver a map of peatland land use in Ireland for 2005/6. This map may be used to aid the management of Ireland's Land Use, Land Use Change and Forestry (LULUCF) requirements and greenhouse gas inventories for the EU 2030 Climate and Energy Framework (European Parliament, 2018). The objective of this research was to develop a map of peatland land use in Ireland using a combination of peatland maps, object-oriented image analysis (OBIA) and medium resolution satellite data.

Material and Methods

Study area

This research focuses on peatlands in the Republic of Ireland as delineated by the DIPMv2 (Connolly and Holden, 2009). Ireland is located between 51°N and 55°N. It has a mild temperate climate (Peel *et al.,* 2007). Precipitation falls predominantly as rainfall with high amounts (up to 3000mm) along the west coast and in mountainous areas (Met Eireann, 2017). Peatlands occur throughout the island but are predominantly found in the west, the midlands and on upland areas (Hammond, 1981). The DIPMv2 maps the extent of three types of peatlands: (i) Raised bog; (ii) Low Level Atlantic blanket bog; and (iii) High Level Montane blanket bog. Raised bogs occur mainly in the midlands of Ireland. Atlantic blanket bogs are located in the West of Ireland, below 160m and High-Level Montane bogs develop in mountainous areas above 160m.

Satellite data

Eight medium resolution IRS-P6 satellite images were acquired over Ireland during 2005 and 2006. The spatial resolution of the IRS-P6 images is 23m (LISS-III). The sensor has four spectral bands: green, red, near-infrared and shortwave infrared bands and a swath width of 142km (Seshadri *et al.,* 2005). These IRS data were chosen over higher resolution SPOT data due to time and funding constraints. The IRS images cover most of the country. However, image acquisition along the western seaboard was limited due to pervasive cloud cover. These peatlands, masked by cloud, cover about 14% of the peatland area and were excluded from the analysis (see Figure 1.). Each IRS image was geo-rectified to the Irish Grid. The DIPMv2 was used to delineate peatlands within each image.

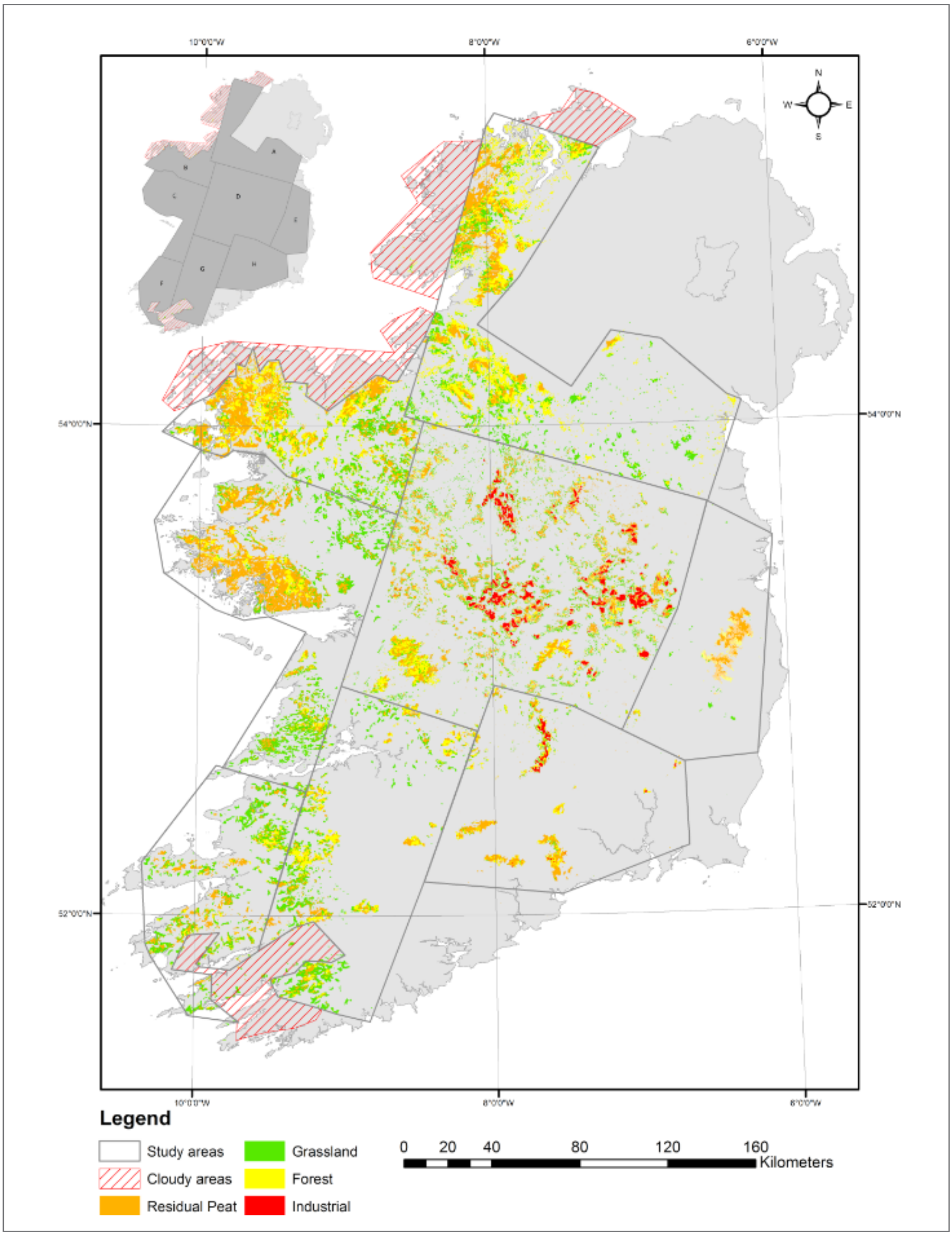

Figure 1: Extent and type of peatland land use in Ireland. Subset Section key: A – Border; B – Mayo; C – Galway/Clare; D – contains both Midlands Raised and Midlands Upland; E – East; F – West Kerry; G – Limerick/Kerry/Cork; and H – South.

Training data

An OBIA approach was used in ArcGIS 9.3 (Feature Analyst (Opitz and Blundell, 2008)). Each IRS image was analysed separately (A–H in Figure 1.). Due to the medium spatial resolution constraints of the IRS imagery only four land use classes could be detected: grassland, forestry, industrial peatlands and residual peatland. The training datasets consisted of polygons representing each land use class. These polygons were digitised by an expert operator with extensive knowledge of land use in Ireland. They were used in the Feature Analyst OBIA to identify areas with similar spectral characteristics. The algorithms used in Feature Analyst are proprietary and implemented within a black box system. However, a number of parameters such as spectral bands, pattern recognition type, masks and output types can be adjusted to enhance the classification. This is an iterative process which enables users to refine initial results by selecting and removing false positives. The refined model can be re-run, enabling the creation of more accurate maps (Güneralp *et al.,* 2014; Opitz and Blundell, 2008). The output map depicts the spatial distribution of land use on peatlands within each image. Each map was amalgamated to create a national scale map of land use on Irish peatlands (Figure 1.).

Accuracy Assessment

An accuracy assessment was carried out on the map derived from each image as well as the overall national scale map. In this study, the confusion matrix was used to derive a series of descriptive and analytical statistics, including the overall accuracy, user's accuracy and producer's accuracy, as well as Cohen's Kappa statistic (Cohen, 1960; Congalton, 1991; Ismail and Jusoff, 2008). Each of these measurements describes how accurate the result is in relation to the real situation on the ground. The overall accuracy is the simplest statistic and describes the proportion of correctly predicted locations (Dzialak *et al.,* 2013). The user's accuracy indicates the probability that a pixel classified on the map actually represents that category on the ground (Congalton, 1991; Story and Congalton, 1986). The producer's accuracy measures the probability that a reference pixel is correctly classified. The final measure that can be extracted from the confusion matrix is Cohen's Kappa statistic. The Kappa statistic shows the proportion of agreement after chance agreement has been removed from consideration (Cohen, 1960). Cohen suggested the Kappa result be interpreted as follows: values ≤ 0 as indicating no agreement and 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement (McHugh, 2012).

A confusion matrix was created for each individual map as well as the amalgamated national scale map (Table 1 and 2). The data for these matrices was acquired using an unstratified random sample (between 85 and 377 points for each image and over 1700 for the national scale map). These were generated using Hawth's Tools (Beyer, 2004) in ArcGIS 9.3. The number of sample points depends on the spatial extent of peat within each image (i.e., more peat = more sample points). These points were exported to Google Earth, where high resolution imagery was used to determine the land use at each point.

Table 1. Percentage of different land uses within each study area and nationally (figure 1).

Section	Location	Peat	Forest	Grassland	Industrial
A	Border	21%	54%	25%	
B	Mayo	42%	33%	24%	
C	Galway/Clare	52%	10%	38%	
D	Midlands Raised	34%	15%	39%	11%
D	Midlands Upland	28%	45%	27%	
E	East	72%	20%	8%	
F	West Kerry	32%	57%	11%	
G	Limerick/Kerry/Cork	26%	25%	49%	
H	South	77%	18%	6%	
	National	34%	27%	35%	4%

Section D contains both Midland Raised and Midlands Uplands

Table 2. Accuracy assessment confusion matrix for each individual study area and the national map.

Section	Figure 1	User Accuracy				Producer Accuracy				Kappa	Overall
		Grassland	Forest	Peat	Other	Grassland	Forest	Peat	Other		
A	Border	79	60	98		89	76	68		0.67	79
B	Mayo	73	43	87		69	64	73		0.54	70
C	Galway/ Clare	61	82	90		88	38	81		0.63	77
D	Midlands Raised	93	91	57	63[1]	81	82	86	71[1]	0.72	80
D	Midlands Upland	0	71	74		0	65	74		0.76	66
E	East	89	79	100	72[2]	62	88	78	100[2]	0.77	84
F	West Kerry	74	70	84		82	70	74		0.62	77
G	Limerick/ Kerry/Cork	78	89	96		97	64	93		0.78	86
H	South	72	59	80		80	53	81		0.65	76
	National	76	65	83	92[1]	80	68	79	73[1]	0.66	77

[1]Industrial Peatlands, [2]Heather. Section D contains both Midland Raised and Midlands Uplands

Results

In Ireland, peatlands land use change is widespread. The map produced in this work is the first to assess the geographical extent of peatland land use and land use change. Land use and land use change was detected on 66% of cloud free peatlands. It includes grassland (35%: ~437,000ha), afforestation (27%: ~337,000ha) and Bord na Móna's industrialised peat extraction areas (4%: ~50,000ha) (Figure 1.). Also, the 34% of residual peatland is probably not in a pristine condition. It may be degraded through small scale impacts, e.g., domestic peat cutting, which are not detectable with the EO data used here (Renou-Wilson *et al.,* 2011). The type and amount of land use change on peatland varies through the country as can be seen in Table 1. Along the Border areas, peatlands have experienced high amount of land use change, e.g., afforestation is 54% and grassland is 25% (Figure 1. Section A.). Grasslands account for much of the land use change in the Galway/Clare area, particularly in east Galway and in Clare (Figure 1. Section C.). 11% of raised bogs in the midlands area have been exploited for electricity production and horticultural products (Figure 1. Section D.). At the national scale, 4% of raised bogs have undergone land use change. Peatland in West Kerry has experienced high land use change to forestry (57%) (Figure 1. Section F.). The South, particularly in the mountainous areas, has relatively low rates of land use change with forest and grassland at 18% and 6% respectively (Figure 1. Section H.). The peatland areas that have been least affected by land use change include: those located in mountainous areas in the south and east of the country as well as in Connemara, where high rainfall and relative remoteness may have made land use change uneconomic.

An accuracy assessment was conducted for each map area as well as for the national area. In the national map, the overall accuracy was 77%. Most of the individual maps have at least an overall accuracy of 76%, with up to 86% in some areas. However, the Mayo map had a relatively low accuracy at 70% (Table 2). The Kappa statistic was predominantly greater than 0.61, indicating substantial agreement between the validation data and maps. However, this was also lower (0.54) in Mayo.

Discussion

Land use change has been occurring on Irish peatlands since at least the early 1800s (Carroll-Burke, 2002; Eaton *et al.,* 2008). While the drainage of peatlands for agriculture has occurred for centuries, drainage for forestry and large scale industrialisation is predominantly a 20th Century development (Carroll-Burke, 2002; Farrell and Boyle, 1990; Renou and Farrell, 2005). Figure 1 shows that the geographical location of peatland land use change is highly fragmented. However, broad patterns are evident. Peatlands in east Galway, Clare, Kerry, Cork and along the border (Figure 1. Sections A, B, C, F and G) have been converted to grassland. Land use change in these areas is probably related to land reclamation schemes developed prior to the 1940s. Large scale and relatively rapid land use changes began with the industrialisation and afforestation programmes of the 1940s and 1950s. The development of a 'peat fuel industry' in the 1940s (Hammond,

1979) led to the rapid exploitation of the raised bogs, predominantly in the midlands. While the peatland afforestation programme, which began in the 1950s, led to land use change on almost 350,000ha of peatland by 2000 (Black *et al.,* 2008; Farrell and Boyle, 1990). A broad scale pattern of forestry land use change can be seen along the border and in upland areas across the country. In the midlands, small areas of cutaway peatland have been converted to grassland but the majority of cutaway has been used for forestry (Renou *et al.,* 2006). Residual peatlands are found predominantly in upland areas and along the west coast, though there are some areas in the midlands. While these broad patterns are evident, peatland land use change has led to the development of a complex heterogenous pattern of degradation at the local level and, particularly, in raised bogs areas in the midlands (Connolly and Holden, 2011a)

The recent amendment to the EU's 2030 climate and energy framework means that these patterns of land use must be mapped to account for emissions and removals of greenhouse gases (GHGs) from peatlands (European Parliament, 2018). Each country must now report those emissions and removals in relation to the 2005-2009 baseline. The methodology outlined here may aid countries with that task. The results, using a combination of peatland map, satellite data and image analysis, show land use change on about two thirds of peatland areas for the 2005/6 period, with 27% of peatlands afforested; 35% converted to grassland; and 4% exploited for industrial use. The Derived Irish Peatland Map V.2., estimates Irish peatlands to extend to 1,466,469ha (Connolly and Holden, 2009). In this study, cloud covered 198,870ha (13.73%) of the peatland area. In the cloud free areas, ~337,000ha of peatland had been afforested; ~437,000ha have been converted to grassland; and ~50,000ha had been developed by Bord na Móna. If the overall accuracy (85%) of the DIPMv2 is taken into account, at least 700,000ha of peatlands have undergone land use change. This work shows that there has been a change in land use on peatlands over the last 200 years, with a relatively rapid change in the last 70 years associated with industrialisation and afforestation. These land use changes impact on the ability of peatlands to sequester and store carbon and there are implications for peatland greenhouse gas dynamics.

Land use: Grassland

The conversion of peatlands to grassland has occurred since at least the early 1800s, but small scale 'reclamation' probably started from the mid-1600s (Carroll-Burke, 2002; King, 1685). This work shows that 35% of peatlands (513,264ha) have been converted to grassland. The areas that see the highest levels of conversion are agricultural areas associated with dairy and beef. In the Limerick/Kerry/Cork area (Figure 1. Section G.), 49% of peatlands have been converted to grassland. O'Sullivan *et al.,* 2015 developed an indicative land use map of Ireland. However, they exclude grass occurring on peat and Natura 2000 designated grass. Renou-Wilson *et al.* (2018) estimated that between 300,000 and 375,000ha of organic soils were under grassland. Historically, landlords drained peatlands for grassland to gain economic advantage (Carroll-Burke, 2002). Throughout the midlands of Ireland and in the Galway/Clare area, it is the edges of the raised bogs that may have been converted to grassland. Initial investigations using the Bog Commissioner maps show that these areas were cut, historically, for fuel (Eaton *et al.,* 2008) and as the peat bank retreated further into the raised bog, the remaining land was converted to grassland – an early case of 'afteruse' (Collier and Scott, 2008; Joynt, 1865; Renou-Wilson *et al.,* 2018). Much of the drainage to grassland may have occurred prior to the Great Famine, when an expansion in agriculture and increases in population forced people to farm on marginal land (Carroll-Burke, 2002; Hall, 2006). However, small scale conversion to grassland still occurred in the 20th Century (Renou *et al.,* 2006).

Land use: Forestry

The afforestation of peatlands began in earnest in the 1950s and, by the year 2000, almost 300,000ha of peatlands had been afforested (Black *et al.,* 2008; Farrell and Boyle, 1990). This work estimates that 27% of peatlands (ca. 395,000ha) were under forestry by 2005/6. However, Renou-Wilson *et al.* (2018) estimate the figure to be just over 320,000ha. One of Ireland's goals, supported by European agricultural policy, was to increase forest cover (Upton *et al.,* 2014). Ireland's policy focused on expanding forest cover by planting on sub-marginal land, often on Montane blanket bogs (Upton *et al.,* 2014). The vast majority of afforestation was carried out by the State forestry company until the late 1980s when private afforestation began to be supported under the EU co-funded Western Package Scheme. Public planting ended in the mid-1990s (Upton *et al.,* 2014). Many of these private schemes were offered on 'lands marginal for agriculture' (DAFM, 2018). However, the high biodiversity value of marginal land is now recognised, forestry is seen as a threat to peatlands and State afforestation grants are no longer offered for these areas (DAFM, 2018; NPWS, 2013).

Land use: Industrial

Up to 4% of peatlands in Ireland have been converted to industrial peatlands by Bord na Móna. This process began in the 1940s (Hammond, 1979). Since then, 40,000ha of peatlands will have been exploited for fuel, electricity production and horticultural products. The DIPM (Connolly *et al.,* 2007) derived the extent of industrial peatlands from Hammond's Peatland Map of Ireland (1979). As peat extraction is due to cease in 2030, much of the peatland area will undergo further land use change from peat extraction to wetlands or willow for biomass burning (Bord na Móna, 2018).

Land use: Residual Peatland

The fourth land use type examined in this study is residual peatland, which covers 34% of the national area. The NPWS (2013) status of habitats states that there is extensive degradation on peatlands and they get a 'bad' status in the habitat reports. According to Malone and O'Connell (2009), just over 600,000ha of peatlands have been affected by domestic peat extraction. However, in this paper, these relatively small scale changes (i.e., peat extraction or erosion) are indistinct due to the spatial resolution of the satellite data (Foody and Boyd, 1999; Shalaby and Tateishi, 2007). Further work, using high resolution UAV, aerial or satellite imagery, is needed to quantify the extent of these small-scale types of degradation and land use change.

Implications of Research

The map developed here depicts the spatial extent and location of four peatlands land use types. It has the potential to help policy makers achieve enhanced decisions in relation to legislative demands, including those associated with the Habitats Directive and the 2030 climate and energy framework. The identification of land use type on peatlands helps to quantify both the quality of the ecosystem and the ecosystem services that can be delivered, i.e., climate regulation, biodiversity and water filtration (Hampton, 2008; Joosten *et al.,* 2012; Maltby and Acreman, 2011; NPWS, 2015) and can, in combination with land use emission factors, refine and quantify GHG emissions and removals from peatlands.

Almost all land use change on peatlands begins with drainage. This lowers the water table and allows forestry, peat extraction and grass growth (Connolly and Holden, 2017). However, drainage and land use change reduce the peatland's ability to sequester and store carbon. The EU recognises that wetlands are effective ecosystems for storing carbon (European Parliament, 2018). Lower water tables lead to the decomposition of stored carbon increasing carbon dioxide (CO_2) emissions (Moore and Davala, 1993). Land use change degrades the peatland habitat, reducing peatland plant communities that sequester atmospheric CO_2. Industrial extraction is the most extreme form of land use change in Ireland. The entire ecosystem may be removed, leading to a drastic reduction/reversal in the climate regulation capacity (Wilson, 2018). However, even small-scale drainage can lead to a reversal of the sink potential of a peatland (Regan *et al.,* 2018). Current management practices on degraded peatlands lead to significant hotspots for CO_2 with annual emissions of 3MtC (Wilson *et al.,* 2013, 2015). Drainage also increases dissolved organic carbon in the water exiting the peatland (Regan *et al.,* 2018). Degraded peatlands are vulnerable to climate change (Turetsky *et al.,* 2002). Projected climate patterns for Ireland show summer temperature increases and precipitation decreases (Nolan, 2015). Models show that the geographical distribution of peatlands is likely to decrease under current scenarios for climate change (Coll *et al.,* 2014; Gallego-Sala *et al.,* 2010). This will impact peatlands particularly east of the Shannon River (Wilson, 2018).

Future work:

The 2030 climate and energy framework now states that GHG emissions and removals from managed wetlands must be reported from 2021 (European Parliament, 2018). At an EU scale, the methodology developed here could be applied across Europe using the peatland map of Europe (Tanneberger *et al.,* 2017) and satellite data. This could aid the development of baseline data, the identification of land use and land cover on these peatlands and lead to the quantification of emissions and removals of GHGs. In Ireland, work may be conducted to integrate emission factors for peatland land use types to develop maps and a data-base of emissions and removals from peatlands, thus aiding the development of baseline data for the climate and energy framework.

However, there are several areas of uncertainty that need to be addressed. The cloud cover issue needs to be addressed to include those peatlands obscured by cloud. Also, the definition of managed wetlands is vague in the EU documentation. Here in Ireland it could include all Bord na Móna's land holding; managed forests on peatlands; managed grasslands on peatlands; peatlands that are managed for domestic extraction, recreation and research as well as those managed under the National Parks and Wildlife Service and Natura 2000. The second area of uncertainty is in relation to the extent of peatlands in Ireland. The DIPMv2, used here, shows that peatlands cover about 20.6% of the national land area. However, Connolly and Holden (2009) suggest that the peatlands could extend to 25%. This needs clarification. Small scale land use change is probably occurring on the residual peatland areas. High resolution imagery will be needed to map and monitor this activity. There is significant opportunity to develop detailed peatland land use maps given the availability of high resolution data from UAV, aerial photography (Loughran, pers comm.) and satellite data (Crosher, 2016). These data will also be useful for identifying carbon hotspots, assessing ecosystem services and identifying areas suitable for conservation or restoration.

The quantification of emissions and removals from wetlands needs an integrated monitoring programme which includes: (i) the refinement of the spatial extent of peatlands in Ireland; (ii) fine scale mapping of land use type and habitat mapping (using high resolution imagery and ground survey) for all peatland areas; (iii) the development of a network of in-situ monitoring infrastructure across Ireland to capture data on GHG emissions and removals; and (iv) the development of models to assess and upscale peatland land use GHG data to quantify emissions and removals from Irish peatlands at a national level. Such a programme would help to address requirements related to the 2030 climate and energy framework as well as the EU's Nature Directives, Biodiversity Strategy and Ireland's National Peatland Strategy. The protection and restoration of peatlands may increase their resilience and lead to the removal of GHGs and a reduction of emissions in the LULUCF sector (European Parliament, 2018). This should be the highest priority in the mitigation of peatland impacts on climate change (Gallego-Sala *et al.,* 2018).

Conclusion

In this work, a map of peatland land use was created using a combination of peatland maps and satellite data for 2005/6. This is the first map of the spatial extent and location of land use types on peatlands for Ireland. The map indicates the types of land use that occur on Irish peatlands and include: grassland, forestry, industrial extraction and residual peatland. These processes of land use change have been ongoing for centuries, primarily to reclaim land for agriculture. In the middle of the 20th century, rapid land use change occurred, primarily to exploit peatlands for fuel and forestry. In this study, medium resolution imagery was used to detect broad scale peatland land use and land use change. These results may be used to aid assessment of Ireland's obligations regarding both the Paris Agreement and the 2030 climate and energy framework. Future work includes using high resolution imagery to refine peatland land use maps. The approach taken in this study could be a useful aid in the assessment of land use and land use change on peatlands across Europe.

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