Mapping peat soils in Ireland: updating the derived Irish peat map

John Connolly and Nicholas M. Holden*

Bioresources Research Centre, Biosystems Engineering, UCD School of Agriculture Food Science and Veterinary Medicine, University College Dublin, Belfield, Dublin

Determining the spatial extent of peat soils is essential for measuring soil carbon (C) stocks. The Derived Irish Peat Map (DIPM) estimated the spatial extent of peat soils as 13.8% of the national area. The DIPM was derived from the Peatland Map of Ireland, CORINE land cover database (CORINE) 1990 and the General Soil Map of Ireland. This paper presents an updated version, the Derived Irish Peat Map Version 2 (DIPMV2), using the same rules-based decision tree methodology, but CORINE 2000 and the Indicative Soil Map of Ireland (ISMI) replaced CORINE 1990 and the General Soil Map of Ireland. The DIPMV2, a best-estimate, illustrates that peat soils occur more extensively than previously mapped, especially in the ‘drumlin belt’ of counties Cavan, Monaghan and Louth. The producer, user and overall accuracies are 88, 91 and 85%, respectively. This is an improvement on the DIPM (87, 84, and 85%). The DIPMV2, estimates that peat soils cover 1,466,469 ha, or 20.6%, of the national land area. The DIPM methodology may provide a long-term tool for updating national peat soil map data. It can be concluded that data for peat soils will become more important because peat has high carbon density and modifications to peat soils have implications for climate change.

Keywords: peatland extent; mapping; GIS; DIPM; Ireland

Introduction

Determining the spatial extent of peat soils is important for soil carbon (C) stock inventories. For the purposes of this work, the definition of peat, peat soil and peatland were based on those decided by a panel of peatland experts from Ireland brought together as a part of the EPA-funded Bogland Project. Peat was defined as a sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material. A peat soil was defined as organic soil materials which have sedentarily accumulated and have at least 30% (dry mass) organic matter over a depth of at least 45 cm on undrained land and 30 cm deep on drained land (Hammond 1979); the depth requirement does not apply in the event that the peat layer is over bedrock. A peatland was defined as a geographical area where peat soil occurs, and for mapping purposes a peatland should cover a minimum spatial extent of 1 ha. Peatlands cover relatively small areas of the globe, at only 4-6% of the terrestrial land area, however they contain nearly one third of the terrestrial soil carbon stock (Gorham 1991, Mitra et al. 2005). At the UN Climate Change conference in Bali in December 2007 the importance of peatlands was reiterated in regard to their capacity to sequester, store and emit carbon (Djoghlaf 2007).
peatlands can function as a persistent sink for atmospheric CO₂ (Tolonen and Turunen 1996, Clymo et al. 1998, Waddington and Warner 2001) and source for CH₄ (Huttunen et al. 2003).

In Ireland, peat soils cover between ~14% (Connolly et al. 2007) and 17% (Hammond 1979) of the national land area. Hammond’s (1979) Peatland Map of Ireland was compiled using disparate sources of data ranging from soil and aerial photo surveys to historical data. Connolly et al.’s (2007) map excluded peat soils that have been subject to industrial extraction. Therefore it is possible that neither of these maps includes all peat soil areas. The calculation of the spatial extent of peat soils is integral to the calculation of peat SOC stocks (Tomlinson 2005). The peat soil organic carbon (SOC) stock was recently estimated by two studies as being 1071.13 Mt C and 1503 Tg C or 53% and 62% of the national SOC stock (Tomlinson 2005, Eaton et al. 2008). These studies used two different methods to estimate peatland extent. Tomlinson (2005) used a 2x2 km grid derived from a range of sources including county soil maps, the General Soil Map (GSM) and for border counties 1:50,000 soil maps for Northern Ireland were used in conjunction with till and geology maps to refine the GSM. Eaton et al. (2008) used CORINE 2000 to estimate the extent of peatlands. These map sources may not cover the full spatial extent of peat soils in Ireland and therefore the peat SOC stock may be underestimated.

Recent work by Connolly et al. (2007) used a GIS rules-based decision tree methodology to estimate the extent of peat soils in Ireland, and produced a map called the Derived Irish Peat Map (DIPM). The rules-based decision tree was constructed in a GIS, using the concept that if at least two sources of data showed that peat was present at a particular location then there was a high likelihood of peat being present at that location on the ground. The advantages of this method are that disparate sources of data can be used to create best-estimates of peat extent, and as new data become available the DIPM can be updated.

Connolly et al. (2007) used landcover maps, CORINE 1990 (O’Sullivan 1994) and soil maps, the Peatland Map of Ireland (PMI) (Hammond 1979), the General Soil Map of Ireland (GSM) (Gardiner and Radford 1980) to derive the DIPM. CORINE 1990 is a landcover map and as such does not record the soil type beneath that landcover. Therefore the CORINE 1990 peatland spatial extent is lower than that of other soil and peatland maps. To account for this issue a map called peat associated vegetation class (PAVC) was developed to ensure that peat soil areas with CORINE landcover classes such as transitional woodland scrub, pasture and coniferous forest, were be included in the DIPM process (Connolly et al. 2004). The DIPM estimated that peat soil extent in Ireland was ~13.8%, but industrial peatlands were excluded. There are a number of issues with the DIPM with regard to resolution, ground-truthing and quality control. Each of the sources map soil and peat soil at a relatively coarse level. Both the PMI and the GSM are mapped on a scale of 1:127560 while CORINE 1990 has a mapping unit of 25 ha. The GSM and PMI were not the result of a comprehensive soil surveys, the GSM was only surveyed for 44% of Ireland. Therefore the extent of peat mapped is only as good as the source data. This short paper addresses some of these issues. Since publication of the DIPM, two new sources of map data have been made available; the Indicative Soil Map of Ireland (ISMI) (Reamonn Fealy, personal communication by email) and CORINE 2000 (EPA 2003). Both of these maps are more detailed in relation to peat soil extent, in comparison to the General Soil Map or CORINE 1990, and in spatial
resolution. The ISMI has a mapping unit of 1 ha and CORINE 2000 is mapped to level 6, whereas CORINE 1990 was mapped to level 3. The inclusion of ISMI introduced extensive small area inter-drumlin peat soil deposits around the border counties of Cavan and Monaghan. The reason for this is that ISMI has a much smaller minimum mapping unit (1–5 ha) than either CORINE 2000 (25 ha) or the Peatland Map of Ireland (unspecified). These small areas of peat soil coincide with soil associations in the GSM that have peat deposits ranging from 10% and 25% of the association for that area, although the GSM categories are broad and do not have specific location for peat. Therefore the objective of this paper is to evaluate how revision of the DIPM using these new data sources influences the estimation of the spatial extent of peatland in Ireland.

Materials and Methods

The rules-based decision tree methodology developed by Connolly et al. (2007) to integrate multi-source data in a GIS was adapted slightly (Figure 1), for use with the new data sources. The Derived Irish Peat Map Version 2 (DIPMV2) used the ISMI

![Diagram](https://via.placeholder.com/150)

Figure 1. The rules based decision tree methodology, modified from Connolly et al., PMI is the Peatland Map of Ireland, ISMI is the Indicative Soil Map of Ireland (2007).
and CORINE 2000 replacing the General Soil Map of Ireland and CORINE 1990 that were used in the DIPM. Both of the new maps were acquired in a digital format and were geo-rectified to the Irish National Grid (a Transverse Mercator projection). New PAVC maps were created, in the decision tree process, by determining where peat was present on both the ISMI and the Peatland Map of Ireland. The PAVC maps were used to identify areas in CORINE 2000 that may contain peat soils but which are masked by the landcover. This fulfils the original rule, described in Connolly et al. (2007), where a peat soil must be present on at least two map sources. The resulting combination peat map was used to examine which CORINE 2000 landcover classes could be associated with peat soils (only classes with a total area over 10,000 ha were included). The Peatland Map of Ireland (PMI) (Hammond 1979) was the fourth map used. Each of the maps was rasterised to allow the use of map algebra in the methodology.

Inclusion of the new data sources introduced a number of new areas of peatland in preliminary versions of DIPMV2, particularly in the ‘drumlin belt’ of counties Cavan, Monaghan and Louth, so additional field sampling was conducted in those regions to complement the field data used by Connolly et al. (2007). Fifty sample points were randomly selected in the GIS within a 100 m buffer zone on either side of a road. The occurrence or absence of peat was examined at each point. The proximity to roads was required to ensure that site access was possible in all cases. Given time and financial constraints, this was the best method for determining the occurrence of peat. However, it should be noted that peat soils located near roads may be more likely to be disturbed.

The first part of the rules-based methodology (Figure 1) contains three steps and acts to filter peat and non-peat areas. Six output maps are produced representing different combinations of the three input maps and the PAVC maps. Nine different combinations (Table 1) of these six output maps were examined to determine which combination gave the most accurate result for the extent of peatlands.

Due to a degree of uncertainty surrounding the occurrence of peat within smaller peat soil areas in the ISMI it was decided to exclude contiguous areas of peat soils that were less than 7 ha in extent. They may be included in future maps as more accurate data become available for these areas. The 7 ha value was derived from field observation. The application of this area filter forms the second part of the rule-based methodology. Each of the nine output maps was filtered. The process of excluding the smaller areas was based upon a rule that examined the size of the peatland. An algorithm was developed to exclude the small peatland areas from the map. The first step was to use the aggregate tool in ArcGIS with a cell factor of three to identify small peatland areas. This process produced pixels with a resolution of 300 metres or 9 ha, and each 300 m pixel was classified according to the number of DIPMV2 pixels it contained. Step two filtered the 300 m pixels to exclude those that contained less than seven hectares of peatland. Finally, the remaining pixels, containing at least seven hectares of contiguous peat, were used to select which pixels were to be kept in DIPMV2.

The overall, producer’s and user’s accuracy were examined to determine which combination of individual maps, filtered or unfiltered, produced the most accurate map of peat soils in Ireland (DIPMV2). This process used a database of over 1400 known peat points from data sampled in this work and by Connolly et al. (2007). To calculate these accuracies the following equations were used:
Table 1. Accuracy assessment of map combinations derived from the procedure in Figure 1. PMI is the Peatland Map of Ireland, ISMI is the Indicative Soil Map of Ireland and PAVC is a Peat associated Vegetation Class.

<table>
<thead>
<tr>
<th>Map #</th>
<th>Map Combination</th>
<th>Overall %</th>
<th>Producers %</th>
<th>Users %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIPM</td>
<td>3 + 2</td>
<td>85</td>
<td>87</td>
<td>84</td>
</tr>
<tr>
<td>1</td>
<td>3 + 2</td>
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<td>86</td>
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<td>4</td>
<td>3 + 2 _ 2 + 2 _ 3 + P</td>
<td>84</td>
<td>81</td>
<td>88</td>
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<tr>
<td>5</td>
<td>3 + 2 _ 2 + 2 _ 3 + P + P</td>
<td>83</td>
<td>82</td>
<td>85</td>
</tr>
<tr>
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<td>3 + 2 _ 2 + 2 _ 3 + P + P + P</td>
<td>86</td>
<td>90</td>
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<td>8</td>
<td>3 + 2 _ 2 + P + P</td>
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<td>9</td>
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<td>11 plus spatial filter</td>
<td>84</td>
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<td>87</td>
</tr>
</tbody>
</table>

Where

3 All three map sources
21 CORINE2000 + ISMI
22 PMI + ISMI
23 PMI + CORINE2000
P1 PMI + PAVC
P2 ISMI + PAVC

Overall accuracy = correctly classified pixels/total number of pixels

Producer’s accuracy = (number of pixels correctly classified as peat soil)/(number ground reference pixels in peat soil)

User’s accuracy = (number of pixels correctly classified as peat soil)/(total number of pixels classified as peat soil)

The map with the most accurate combination of the overall, producer’s and user’s accuracy was adopted as DIPMV2. The spatial extent of the DIPMV2 was compared with the DIPM to determine what effect the use of ISMI and CORINE 2000 had on the spatial extent of peat soils in Ireland.

Results

This methodology is based on the concept that a peat soil will be included if it is present at the same location on at least two maps. Each of the steps in the
rules-based methodology produces either one or several maps. Rule 1 produces one map (3) in which peat soil is present at the same location on all three input maps. Rule 2 produces three maps (21, 22, 23) where peat soil is present at the same location on two of the input maps. Rule 3 produces two maps (P1 and P2) where peat soil is present on either the PMI or the ISMI and a PAVC. Nine output maps, representing combinations of each rules outputs, were produced and the spatial filter described above was applied to these. The overall, user and producer accuracies were examined for each of the eighteen maps (Table 1).

In the DIPMV2 the differences between the map accuracies in Table 1 are small. As an example, the accuracy assessment for map 9f compared with map 7f reveals the effect that the exclusion of map 23 (CORINE 2000 + PMI) has on the accuracy assessment. In map 20, both the overall and producer’s accuracy are reduced by the exclusion of map 23. However, the exclusion of an output map may lead to a large loss of peat soil area in the combined map and therefore every output map combination was examined visually in the GIS. In this methodology, map 7f gives the best estimate of peat soil extent with an overall accuracy of 88%, a producer’s accuracy of 91% and a user’s accuracy of 85%. The DIPM’s range of accuracies was 85, 87 and 84%. Map 7f also includes many small peat soil areas throughout Ireland that are not present in the Peatland Map of Ireland, CORINE 1990 or 2000 or the General Soil Map of Ireland. Therefore the combination of individual maps in map 7f is considered to be the most accurate available and this map was chosen as the Derived Irish Peat Map Version 2 (DIPMV2) (Figure 2).

Discussion
When the most accurate maps, 6f, 7f and 6, are compared in Table 1, it looks as though map 6 has the best overall accuracy as its user’s accuracy is slightly better than map 7f. This suggests that the P1 combination (PMI + all PAVCs) could be excluded. However, when the map combinations were examined in a spatial sense in the GIS, it was noted that the exclusion of P1 would lead to the exclusion of large areas of peat soil in south-west Cork, so the interpretation of the accuracy values has to be reviewed in light of the spatial patterns produced. Figure 3a and b and Figure 4a and b depict the difference between map 7 and map 7f in different parts of the country. Figure 3a shows the extent of inter-drumlin peat soils that are found in the Monaghan and Cavan regions on the ISMI. The extent of these is reduced with the use of the spatial filter. Similarly in Figure 4, smaller peat soil areas in eastern Mayo, Galway and Roscommon are reduced by using the spatial filtering tool.

The estimate of spatial extent of peat soils in Ireland differs to that given by the DIPM in Connolly et al. (2007). The inclusion of these small peat soil areas in the Cavan and Monaghan region brought the national spatial extent of peat soil up to 1,733,697 ha or ~25% of the country without spatial filtering. This value is nearly 50% greater than previously estimated and therefore it was necessary to conduct fieldwork in order to determine whether this represented an accurate estimate of peat soil extent. Peat was only found at 40% of the 50 sample points visited in the region. This presented a dilemma: should all these small peat soil areas be included even though there was a question as to whether they were peat or not, or should a rule be put in place to exclude them from the map until further more accurate information becomes available? Due to the very high national spatial extent which was estimated if
these peat soils were included it was decided to exclude the smaller peat soil areas using the 7 hectare spatial filter in the GIS as previously described. After filtering, the smaller peat soil areas (<7 ha) were excluded from the final map. In most cases the spatial filtering slightly increased the overall, producer’s and user’s accuracies. The best-estimate of the spatial extent of peat soils in Ireland was...
Figure 3. a) Unfiltered interdrumlin peatlands b) Filtered interdrumlin peatlands.

Figure 4. a) Unfiltered west coast peatlands b) Filtered west coast peatlands.
1,466,469 ha or 20.6% (Figure 2). The peat soil classification used in the legend was applied in the same manner as Connolly et al. (2007). It is clear from this work that more research needs to be conducted on evaluating the small area peat soil in the drumlin belt and throughout Ireland. The national spatial extent of peat soil may increase in future studies if small peat soil areas are included. The role of these peat soils in the national soil carbon budget also needs to be evaluated given their spatial extent and carbon stock.

Both Tomlinson (2005) and Eaton et al. (2008) used different methods to estimate peat soil extent when considering carbon balance from peatlands. Tomlinson (2005) used disparate sources of data including dominant soils in a 2x2km grid square derived from county soil maps and other data, GSM data and a version of the GSM refined by 1:50 000 Northern Ireland soil and till and geology maps. Eaton et al. (2008) calculated the spatial extent from CORINE 2000 levels five and six. The peat soil area depicted in the DIPMV2 is more extensive than that used in those studies and therefore those studies may be underestimating the peat soil C stock in Ireland.

At the recent UN Climate Change conference in Bali the importance of peatlands as a C stock was reiterated. Peatlands have a high C stock to area ratio. In Ireland disturbance of peatlands is widespread, creating issues in regard to the C stock. When peatlands are in a pristine state they can function as a carbon sink, however the disturbance of peatlands, whether it be through drainage, extraction or burning combined with predicted climate change may possibly enhance CO₂ emissions from the large peat soil carbon stock present in Ireland (Davidson and Janssens 2006).

Conclusions
The DIPM (Connolly et al. 2007) represented an update in the process of creating accurate maps of peat soils in Ireland. The DIPM was updated as described in this paper resulting in the DIPMV2, where peat soil extent in Ireland covers approximately 1,466,469 ha or ~20.6% of the country. This value is larger than previous estimates, mainly due to the inclusion of inter-drumlin peatlands of at least 7 ha in size located in the border counties of Cavan, Monaghan and Leitrim and in the west midlands. Nevertheless, this figure may underestimate the true extent of peat soil areas due to uncertainty of the extent of small peat areas within that region. This has implications for the peat soil carbon stock. The larger area of peat soils mapped in this work suggests that there is probably more C stock in Ireland than previously estimated. Peat depth is an important part of the peat soil C stock calculations. Inter-drumlin and other small area peat soils may be quite shallow or cut, and although that in itself may not have a large impact on the C stock, they still extend the peat soil area. More work is necessary to more accurately determine the peat soil extent in Ireland and to determine peat depth data to allow for the accurate estimation of peat soil C stocks.

The rule-based methodology of Connolly et al. (2007) which is adapted here may provide a long-term tool for updating national peat soil map data. This method is flexible and adaptable, facilitating the creation of more accurate versions of the DIPM as new map data sources become available. However, changes in the methodology will need to be made clear rationally and reliably. Ultimately it can be concluded that the availability of reliable data for peat soils will become
increasingly important due to their high carbon density and the implications of this for climate change.

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