Area estimations of cultivated organic soils in Ireland: reducing GHG reporting uncertainties

J. Donlan, J. O'Dwyer and K.A. Byrne

Department of Life Sciences, University of Limerick, Ireland

SUMMARY

Cultivated organic soils, which are a large source of CO_2 emissions, are of particular interest in the Republic of Ireland where peatlands cover 20 % of the landscape. For accurate accounting and national reporting of greenhouse gas (GHG) emissions, there is a need to calculate the total land area used for cultivation activity on drained organic soils. Peatlands (organic soils) in Ireland are also used for arable farming, which results in particularly high greenhouse gas emissions *per* unit area. However, the Irish National Inventory Report to the United Nations Framework Convention on Climate Change lacks mention of this type of land use. The actual area of organic soils under arable land use (cropland) in Ireland has, thus far, not been quantified. Here we provide a first estimate of the area of organic soil that is used for arable farming in Ireland. Through map overlay analysis using GIS in combination with probability sampling and ground truthing, we estimate the area of organic soils under arable cropping at 1,235 ha, which is considerably lower than the estimate of 3,688 ha based on map overlays alone. This research provides information to support improved accounting of organic soils under cultivation and may contribute to reducing uncertainty in national reporting of GHG emissions, thus providing a more reliable basis for strategies aimed at reducing GHG emissions in Ireland in the future.

KEY WORDS: GIS, greenhouse gas inventories, overlay analysis, peat soils

INTRODUCTION

Greenhouse gas (GHG) emissions from land use and land cover change are the second largest source of carbon released to the atmosphere, the largest being emissions from fossil fuel combustion (IPCC 2006). As yet, this is the most uncertain component of global GHG emission estimates (Houghton *et al*. 2012, Peters *et al*. 2012, Le Quéré *et al.* 2015). The difficulties of monitoring and reporting on the land use sector result in large uncertainties within national GHG inventories which obstruct the development of effective mitigation strategies. While guidance on the compilation of inventories is provided by the IPCC 2006 Guidelines (Eggelston *et al*. 2006), reporting requires reliable area information on land use categories. Currently, such data are lacking for arable land on organic (peat) soils in the Republic of Ireland.

A large proportion of Ireland's land mass (20 % of the landscape in total) is covered by peatland (Connolly & Holden 2009), storing between 53 % (Tomlinson 2005) and 61 % (Xu *et al*. 2011) of total soil C stocks. However, much of this peatland has been disturbed and degraded over the years due to land use change, with only 15 % of peatland (approximately 180,000 hectares) remaining in its natural state (Douglas *et al.* 2008). Much of this change arises from the conversion of peatland to grassland and forestry (Renou-Wilson *et al*. 2011), which is known to result in considerable ongoing CO_2 (and N_2O) emissions to the atmosphere (Byrne *et al*. 2004, IPCC 2014).

Nationally, the total cropped area in Ireland (irrespective of soil type) amounts to 378,000 ha or 9 % of the farmed area (Teagasc 2012), and thus represents a substantial proportion of the agricultural sector. Where tillage farming takes place on organic soils, CO_2 (and N_2O) emissions are known to be particularly high (Strack *et al.* 2008).

In the coming years, policies will require the identification of strategies to reduce GHG emissions both in Ireland and across the globe. At the core of these strategies will be multi-sectorial GHG emission reporting with reduced uncertainty. Recently, the role of peatland emissions in particular was given considerable policy impetus by the United Nations Framework Convention on Climate Change (UNFCCC) when it agreed at its December 2011 meeting in Durban that a new activity, 'rewetting and drainage', was to be introduced under the Kyoto Protocol. In support, the Intergovernmental Panel on Climate Change (IPCC) published the 2013 '*Wetlands Supplement*' to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2014), which provides new guidance on estimating and reporting GHG emissions from organic soils.

Given the extent of peatland disturbance in Ireland, restoration and rewetting of organic soils has considerable potential to contribute to the reduction of land-based GHG emissions (*cf*. Wilson *et al*. 2016). The total land use area devoted to cultivated organic soils in the Republic of Ireland has previously not been quantified and is thus omitted from national inventory submissions (EPA 2015), and the role that arable farming on organic soils could play is as yet unknown. Consequently, it is vital to gain a clear understanding of the nature and extent of organic soils used as arable land on a national level.

In this study we estimate the total land area of drained organic soils under cultivation for arable crops in Ireland, and the associated GHG emissions using default emission factors from the *Wetlands Supplement* (IPCC 2014). This research aims to provide an impetus for improved accounting of drained organic soils under cultivation and to promote national reporting of GHG emissions with reduced uncertainty; and thus to provide a more reliable basis for strategies aiming to reduce GHG emissions and for data led land use planning in the future.

METHODS

In order to assess the area of organic soils used as arable land we used a Geographical Information System (GIS) to amalgamate existing data by overlaying land use and organic soil shapefiles for the whole of Ireland, and verified our findings through fieldwork.

Study area and data sources

The study area is the Republic of Ireland, an island with a land area of 70,273 km² of which 20 % is peatland (Connolly & Holden 2009). Agriculture is the dominant land use (64 % of the total land area, CSO 2010). In order to delineate croplands, we used the Land Parcel Identification Scheme (LPIS) data created by the Department of Agriculture, Food and the Marine (DAFM 2012). All analysis involving the LPIS data was carried out by researchers at the Environmental Protection Agency (EPA) in order to comply with data confidentiality agreements. To identify organic (peat) soils, the 1:50,000 habitat map from the EPA Soil and Subsoil Mapping Project (Fealy *et al*. 2009) was chosen. This map delineates particular habitat types using expert rules and known associations of certain habitats with subsoils, land cover, altitude, altitude-related features, and features from Hammond's *The Peatlands of Ireland* map of 1981 (Fealy *et al*. 2009). The 1:250,000 Derived Irish Peat Map II (DIPM) (Connolly & Holden 2009) was used for additional clarification and corroboration of peat occurrence. While the LPIS data were deemed reliable for delineating agricultural activity and, specifically, arable cropping, national data regarding the location of organic soils (peat) are less robust and lack adequate information regarding uncertainty. Therefore, the focus of the accuracy assessment was on the soil type - organic (peat) or mineral - within fields under cultivation for arable crops. The LPIS data were used to locate arable fields and to limit or target sampling to areas within the arable fields. A 100 m buffer around the organic soils delineated on the habitat map was incorporated as a control measure attempting to assess sampling errors of omission (by finding peat where the map describes otherwise). An overlay of the land use and soil maps was created to identify areas under crop cultivation. As a result of the overlay analysis, the target area for this study was found to be 12,600 ha.

Accuracy assessment: analysis and estimation

Due to the combination of three GIS layers for delineation of the target area, with no clear uncertainty information, the uncertainty of the resulting overlay is unknown. Consequently, an accuracy assessment of the spatial overlay was conducted to (a) refine the assessment of cropland on organic soils and (b) estimate the uncertainty of the refined assessment. This assessment was based on a probability sampling method and ground truthing. Ground truthing was limited to arable fields within at least one of the following: (a) habitat map peat class; (b) a 100 m buffer around 'a'; or (c) areas classified as peatland by the DIPM. Sample sites (n = 100) were randomly chosen within the target area on the overlay map and generated using QGIS software. Access to 69 of the 100 sites (n = 69/100) was permitted by landowners (Figure 1). At these sites, the presence of arable land was confirmed and *in situ* visual assessment was used to classify sampled soil as organic or mineral. Results were then compared to the classification on the overlay map. The data collected from the sampling locations will hereafter be referred to as 'reference data' and are similarly classed as 'organic' or 'mineral' (soil). An error matrix was constructed from which accuracy information and an error-adjusted area estimate for drained organic soils under cultivation for arable crops was calculated.

Following Olofsson *et al*. (2013), we calculated an error matrix with error-adjusted proportion, the producer's accuracy (probability that a certain land cover of an area on the ground is classified as such), user's accuracy (probability that a pixel labelled as a

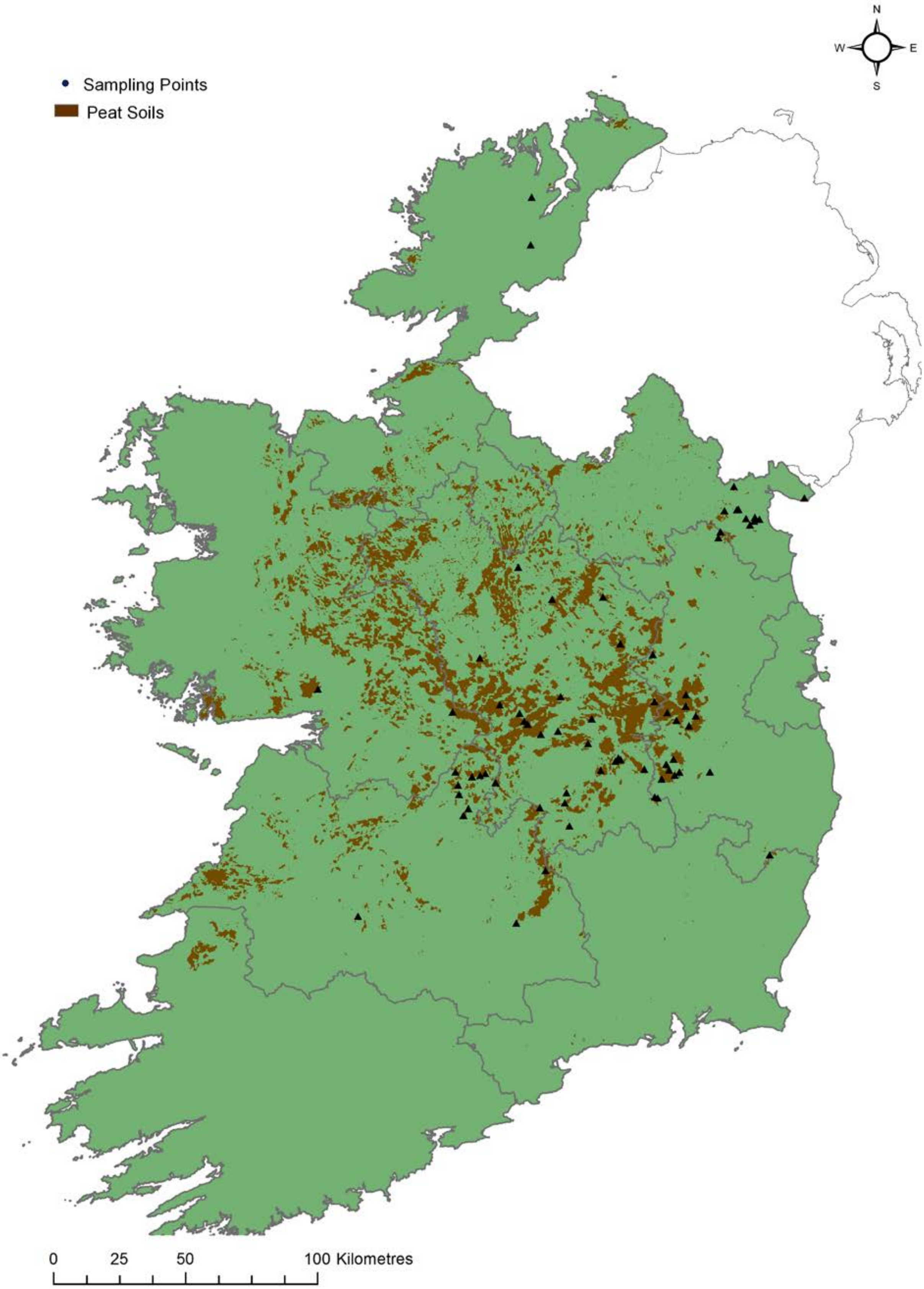

Figure 1. Map of Ireland showing the distribution of organic soils and locations of the 69 sampling points for which field sampling was permissible.

certain land-cover class in the map really belongs in that class) and overall accuracy, as well as area estimations and the resulting confidence intervals.

In order to amend any systematic classification error in the map classes, the cells (Pij) in a matrix of error-adjusted proportions were calculated using the following equation:

$$Pij = W_i \frac{n_{ij}}{n_i} \quad [1]$$

where *i* is a map category (a row in the error matrix), *j* is a reference category (a column in the error matrix), n_i is the number of samples in a map category, and n_{ij} is the total number of samples in map category and reference category (Olofsson *et al*. 2013). W_i is the proportion of the area mapped as Class *i* relative to the total area A_{tot} and n_i, calculated as follows:

$$W_i = A_{m,i} \div A_{tot} \quad [2]$$

where $A_{m,i}$ = mapped area of category *i*, and A_{tot} = total mapped area (target area). The total unbiased area of category (*j*) was calculated as follows:

$$A_j = A_{tot} \times P\cdot_j \quad [3]$$

where $P\cdot_j$ is the column total of area proportion of category (*j*).

The estimated standard errors of the estimated proportion (Equation 4) and the error adjusted estimate of the area (Equation 5) are as follows:

$$S(P\cdot_j) = \sqrt{\sum_{i-1}^{q} W_i^2 \frac{\frac{n_{ij}}{n_i}\left(1-\frac{n_{ij}}{n_i}\right)}{n_i-1}} \quad [4]$$

$$S\left(A_j\right) = A_{tot} \times S(P\cdot_j) \quad [5]$$

The estimated 95 % confidence interval for the estimate of area for category (j) is:

$$A_j \pm 2 \times S\left(A_j\right) \quad [6]$$

Calculation of CO_2 emissions

Total CO_2 emissions from peatlands used as arable land were calculated using our area estimates and the CO_2 emission factor from the *Wetlands Supplement* (IPCC 2014) of 7.9 t C ha^{-1} yr^{-1} (C.I. 6.5–9.4) for drained organic soils utilised as cropland. For comparative purposes, the emission factor was applied to both the area estimated using the reference data and the estimate derived from map data alone.

RESULTS

Accuracy assessment of spatial data

The locations of the 69/100 points where soil samples were collected are shown in Figure 1. Organic soil was found at eight (n = 8/69, 11.6 %) of these locations, seven of which (n = 7/8, 87.5 %) were correctly classified as peat on the habitat map. Organic soil was found at one (n = 1/8, 12.5 %) site that was classified as 'other' on the habitat map. Mineral soil was found at 61 (n = 61/69, 88.4 %) of the sampled locations, eighteen (n = 18/61, 29.5 %) of which were classified as peat on the habitat map. Forty-three (n = 43/61, 70.5 %) sample points were accurately classified as 'other'. Table 1 gives an error matrix summarising these findings.

Of the target area (12,600 ha), the total area classified as peat on the habitat map and DIPM was 3,688 ha (n = 3,688/12,600, 29.3 %), with the remaining 8912 ha (n = 8,912/12,600, 70.7 %) classified as mineral (other). However, based on the reference data obtained from field sampling results, where *in situ* classification of organic soils was assessed, the estimated area of peat in the target area was only 1,235 ha (1,235/12,600, 9.8 %), resulting in a 33.5 % user's accuracy (66.5 % error of omission). The producer's accuracy for peat was 86.6 % (13.4 % error of omission) as a result of one sampling location where peat was found that was classed as 'other' on the habitat map (Table 2).

Table 1. Error matrix based on sample counts, where rows represent map classes and columns represent reference data classes.

Map classes	Reference organic	Mineral	Total
Peat	7	18	25
Other	1	43	44
Total	8	61	69

Table 2. Error matrix based on reference data expressed as estimated proportion of the target area, where rows represent map classes and columns represent reference data classes.

Map data	Reference organic	Reference mineral	Total	User's	Producer's	Overall
Peat	8.20	21.07	29.27	33.5	86.60	
Other	1.61	69.12	70.73	97.73	76.64	
Total	9.80	90.20	1.000			77.32

The new area estimate for organic soils under cultivation includes all areas mapped as peatlands by the habitat map, and corroborated by the DIPM, that lie within areas under cultivation according to LPIS. The maps cover all of Ireland, so our estimate of 1,235 ha (Table 3) refers to the total national area of organic soils under cultivation for arable crops. Estimates for mineral soils (Table 3) are reported for completeness and transparency only.

Quantification of CO_2 emissions from area estimates

The IPCC default CO_2 emission factor for drained organic soils utilised as cropland in both boreal and temperate climates is 7.9 t C ha^{-1} yr^{-1} (C.I. 6.5–9.4). Multiplying our area estimate of 1,235 ha by this emission factor, we arrive at 9.756 Kt C yr^{-1} (SD ± 1.79) emitted as a result of organic soil degradation under arable land use in 2012. Based on uncorrected map data alone, we arrive at 35.98 Kt C yr^{-1} (SD ± 1.8), or 26.22 Kt C yr^{-1} more than based on our corrected area estimate.

Table 3. Estimated area (in hectares) of organic soil under cultivation (2012), based on reference classification and 95 % confidence interval.

Soil	Area (ha)	95% Confidence Interval (ha)	
		lower	upper
Peat	1,235	451	2,012
Mineral	11,365	10,581	12,149
Total	12,600		

DISCUSSION

Uncertainty information is not available for the datasets used in the overlay. However, under the Common Agricultural Policy (CAP), the EU Commission (Council of the European Union 2009) requires that the LPIS maintained by each member state should be completely accurate. It was thus deemed reliable to locate arable fields and limit the target sample set to areas within the arable fields. In terms of the accuracy of the overlay, error results from the inherent error of the base layers and limitations in resolution. The 100 m buffer was incorporated into the study area as a control measure because it was reasoned that sampling within this target area would include a probability of sampling errors of omission without unnecessarily concentrating sampling sites that were less likely to have organic soil.

Of the 100 points selected for ground truthing, we were allowed access to only 69. To avoid disturbance of private property and in order to ensure homogeneity of characterisation across the sampling points, the presence of organic soil was assessed (and the presence of cultivation confirmed) visually for all of these sites. It is important to note that, due to the assessment method, uncertainty does exist in terms of both Type I and Type II errors, as organic soils could have been incorrectly classified in some cases. Accuracy could certainly be increased by taking a larger number of samples, and the results are tentative only, but we consider our 69 samples to constitute a fair representation of the tilled peat soils of the country. As shown in Figure 1, clustered sampling occurred through the midlands of Ireland, which are highly suitable for tillage farming (Teagasc 2012).

Our area estimate for arable land on organic (peat) soil of 1,235 ha (C.I. = 451–2,012) is considerably lower than the area estimate based on mapping alone (3,688 ha). This disparity suggests a systematic error due to misclassification in the habitat map. On the other hand, the reference data represent only a small sample of locations, show large uncertainty, and may provide only a fairly accurate representation of the total area. The much lower area estimate following ground truthing logically results in a much lower estimate of CO_2 emissions. Our estimate of 9.756 Kt C yr^{-1} is small compared to other sources in the Agriculture and LULUCF sectors (EPA 2015). Nonetheless, Ireland has thus far reported that there is no cropland on organic soils, which is apparently incorrect. This deficiency in reporting croplands on organic soils would also seem to warrant close scrutiny of the reported 432.98 kha of forest and the 371.62 kha of grassland on organic soil (EPA 2015).

There is a significant uncertainty with regard to the IPCC default values for CO_2 efflux from cultivated peat soils and direct flux measurements in Ireland are lacking. As a result, quantification of Irish specific emission factors for croplands on peat soils with comparison to the IPCC default values is a warranted area of further research.

While the emissions calculated for cultivated organic soils within this study are small relative to total land use emissions, it is important to consider not only carbon efflux attributed to peatland degradation, but also the loss of the natural carbon influx associated with pristine peatlands (Holden & Connolly 2011). It is well documented that peatland cultivation inevitably leads to loss of the whole peat layer and subsequently high emissions (Regina *et al.* 2015); yet, there are few incentives or regulations to effectively minimise these losses. One possible mitigation strategy could be the promotion of paludiculture; the cultivation of biomass on wet and rewetted peatlands (Wichtmann & Couwenberg 2013, Wichtmann *et al*. 2016). Paludiculture has the potential to sustain the ecosystem services associated with natural peatlands, preserve organic soils in use (Joosten *et al*. 2012), and sustainably harvest biomass for renewable energy or as a raw material (Wichtmann & Wichmann 2011). This could offer a sustainable solution to peatland disturbance from cultivation in Ireland, with fewer negative impacts for the environment and no significant loss in economic value. As an example, the cultivation of common reed (*Phragmites australis*) on rewetted peatland in Germany resulted in a GHG emission reduction of some 15 t CO_2-eq *per* hectare *per* year by significantly reducing the mineralisation of peat (Wichtmann & Wichmann 2011).

Although the rewetting of peatland in Ireland may not typically focus on arable land use, it is important to consider the long term sustainability of the cultivation of organic soils, and to promote changes in land management practices that are conducive to both economic and environmental longevity. Planning for such changes requires accurate estimates of the area of peatland under arable use, and this study provides a first estimate.

ACKNOWLEDGEMENTS

This research was funded by the Irish Environmental Protection Agency Research Programme 2014–2020. We would like to acknowledge Jesko Zimmerman for his help with LPIS data analysis as well as John Couwenberg, another reviewer (anonymous) and the Editor for their constructive comments on earlier versions of this article.

REFERENCES

Byrne, K.A., Chojnicki, B., Christensen, T.R., Drösler, M., Freibauer, A., Frolking, S., Lindroth, A., Mailhammer, J., Malmer, N., Selin, P., Turunen, J., Valentini, R. & Zetterberg, L. (2004) *EU Peatlands: Current Carbon Stocks and Trace Gas Fluxes*. Concerted Action CarboEurope-GHG - Synthesis of the European Greenhouse Gas Budget, Department of Forest Science and Environment, Viterbo, Italy, 58 pp.

Connolly, J. & Holden, N.M. (2009) Mapping peat soils in Ireland: updating the derived Irish peat map. *Irish Geography,* 42(3), 343–352.

Council of the European Union (2009) Council Regulation (EC) No 73/2009 of 19 January 2009 establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers, amending Regulations (EC) No 1290/2005, (EC) No 247/2006, (EC) No 378/2007 and repealing Regulation (EC) No 1782/2003. *Official Journal of the European Union*, L 30/16, 31.1.2009, 16–99.

CSO (2010) *Agricultural Census*. Central Statsitics Office, Dublin, Ireland. Online at: http://www.cso.ie/en/media/csoie/releasespublications/documents/agriculture/2010/full2010.pdf, accessed: 13 Dec 2015.

DAFM (2012) *LPIS Land Parcel Identification Scheme Database*. Department of Agriculture, Food and Rural Development, Department of Agriculture, Food and the Marine, Ireland. Accessed Feb 2013 through the Environmental Protection Agency, Dublin.

Douglas, C., Valverde, F.F. & Ryan, J. (2008)

Peatland habitat conservation in Ireland. In: Farrell, C. & Feehan, J. (eds.) *After Wise Use - The Future of Peatlands*, Proceedings of the 13th International Peat Congress, International Peat Society (IPS), Tullamore, Ireland, 681–685.

Eggelston, H., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (2006) *Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 7. IPCC National Greenhouse Gas Inventories Programme, Hayama, Japan, 24 pp.

EPA (2015) *Ireland's National Inventory Report - Greenhouse Gas Emissions 1990–2013*. Report to the United Nations Framework Convention on Climate Change, Environmental Protection Agency (EPA), Johnston Castle, Wexford, Ireland, xxii + 581 pp. Online at: http://erc.epa.ie/safer/resource?id=b3f720da-4f5c-102a-90c6-0593d266866d, accessed 16 Apr 2016).

Fealy, R.M., Green, S., Loftus, M., Meehan, R., Radford, T., Cronin, C. & Bulfin, M. (2009) *Teagasc-EPA Soils and Subsoils Mapping Project: Final Report, Volume 1*. Unpublished report, Teagasc (Environmental Protection Agency), Carlow, Ireland, 140 pp.

Grønlund, A., Hauge, A., Hovde, A. & Rasse, D.P. (2008) Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods. *Nutrient Cycling in Agroecosystems*, 81(2), 157–167.

Holden, N.M. & Connolly, J. (2011) Estimating the carbon stock of a blanket peat region using a peat depth inference model. *Catena*, 86(2), 75–85.

Houghton, R.A., House, J., Pongratz, J., Van der Werf, G., DeFries, R., Hansen, M., Quéré, C.L. & Ramankutty, N. (2012) Carbon emissions from land use and land-cover change. *Biogeosciences*, 9(12), 5125–5142.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (5 volumes). Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (eds.), IGES, Japan. Online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html, accessed 23 Mar 2016.

IPCC (2014) *2013 Supplement to the 2006 Inter-Governmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories: Wetlands*. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. & Troxler, T.G. (eds.), IPCC, Switzerland. Online at: http://www.ipcc-nggip.iges.or.jp/public/wetlands/index.html, accessed 23 Mar 2016.

Joosten, H., Tapio-Biström, M.-L. & Tol, S. (eds.) (2012) *Peatlands - Guidance for Climate Change Mitigation through Conservation, Rehabilitation and Sustainable Use*. Mitigation of Climate Change in Agriculture (MICCA) Programme, FAO/Wetlands International, Rome, 100 pp.

Kasimir-Klemedtsson, Å., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J. & Oenema, O. (1997) Greenhouse gas emissions from farmed organic soils: a review. *Soil Use and Management*, 13(s4), 245–250.

Le Quéré, C., Moriarty, R., Andrew, R.M., Canadell, J.G., Sitch, S., Korsbakken, J.I., Friedlingstein, P., *et al*. (2015) Global Carbon Budget 2015. *Earth System Science Data*, 7, 349–396.

Olofsson, P., Foody, G.M., Stehman, S.V. & Woodcock, C.E. (2013) Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment*, 129, 122–131.

Peters, G.P., Marland, G., Le Quéré, C., Boden, T., Canadell, J.G. & Raupach, M.R. (2012) Rapid growth in CO_2 emissions after the 2008–2009 global financial crisis. *Nature Climate Change*, 2(1), 2–4.

Regina, K., Budiman, A., Greve, M.H., Grønlund, A., Kasimir, Å., Lehtonen, H. & Wösten, H. (2015) GHG mitigation of agricultural peatlands requires coherent policies. *Climate Policy*, 1–20.

Renou-Wilson, F., Bolger, T., Bullock, C., Convery, F., Curry, J., Ward, S., Wilson, D. & Müller, C. (2011) *BOGLAND: Sustainable Management of Peatlands in Ireland - Final Report*. STRIVE Report 75, Environmental Protection Agency, Johnstown Castle, Co. Wexford, Ireland, 157 pp.

Strack, M., Waddington, J., Turetsky, M., Roulet, N. & Byrne, K. (2008) Northern peatlands, greenhouse gas exchange and climate change. In: Strack, M. (ed.) *Peatlands and Climate Change*, International Peat Society, Jyväskylä, Finland, 44–69.

Teagasc (2012) *Tillage Sector Development Plan 2012*. Report, Teagsc Tillage Crop Stakeholder Consultative Group, Johnstown Castle, Wexford, Ireland, 51 pp. Online at: http://www.teagasc.ie/publications/2012/1602/Tillage_Sector_Plan_2012_FINALlowres.pdf, accessed 20 April 2016.

Tomlinson, R. (2005) Soil carbon stocks and changes in the Republic of Ireland. *Environmental Management*, 76(1), 77–93.

Wichtmann, W. & Couwenberg, J. (2013) Reed as a renewable resource and other aspects of paludiculture. *Mires and Peat*, 13(00), 1–2.

Wichtmann, W. & Wichmann, S. (2011)

Environmental, social and economic aspects of a sustainable biomass production. *Journal of Sustainable Energy & Environment*, Special Issue 1, 77–81. Online at: http://www.jseejournal.com/JSEE%202011/Special%20Issue/19.%20Environmental,%20social_Wichtmann_p.%2077-81.pdf, accessed 22 Apr 2016.

Wichtmann, W., Schröder, C. & Joosten, H. (eds.) (2016) *Paludiculture – Productive Use of Wet Peatlands*. Schweizerbart Science Publishers, Stuttgart, Germany, 272 pp.

Wilson, D., Blain, D., Couwenberg, J., Evans, C.D., Murdiyarso, D., Page, S.E., Renou-Wilson, F., Rieley, J.O., Sirin, A., Strack, M. & Tuittila, E.-S. (2016) Greenhouse gas emission factors associated with rewetting of organic soils. *Mires and Peat*, 17(04), 1–28.

Xu, X., Liu, W., Zhang, C. & Kiely, G. (2011) Estimation of soil organic carbon stock and its spatial distribution in the Republic of Ireland, *Soil Use Management*, 27(2), 156–162.

Submitted 26 Feb 2016, final revision 27 Jun 2016
Editor: Olivia Bragg

Author for correspondence:
Dr Ken Byrne, Department of Life Sciences, University of Limerick, Limerick, Ireland.
Tel: +35387 908 6967; E-mail: Ken.Byrne@ul.ie