Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Call 2022 –
- Final Report -

Lead Applicant Name	Eve Daly
Host Organisation name	University of Galway
Project Title	Mapping peatlands on a national scale using airborne Geophysical data
Contract Number	2022-SC-015

Co-Applicant Name	John Connolly
Host Organisation name	Trinity College Dublin
Project Title	Mapping peatlands on a national scale using airborne Geophysical data
Contract Number	2022-SC-015

Co-Applicant Name	Louis Gilet
Host Organisation name	Trinity College Dublin
Project Title	Mapping peatlands on a national scale using airborne Geophysical data
Contract Number	2022-SC-015

This report covers the period 1st December 2022 to project end date (31/07/23)

Research Programme
- Short Call 2022 –
Final Report

1. ***Staff hired/funded by the project (copy table as needed)**:

Name	Dave O'Leary
Position	Research Assistant
Role in the project	Research Assistant
Contract start date	01/02/2023
Contract end date	31/07/2023
Gender:	☒ Male ☐ Female ☐ Other/non-binary ☐ Prefer not to say

2. **(a) Project information**:

Final project report (*max **2500** words, excluding figures and headings*):

Executive summary:

Compliance with the Paris Agreement implies carbon neutrality by 2050–2070 (IPCC, 2018) meaning that 500,000 km² of drained peatlands need to be rewetted (Kreyling et al., 2021) to reduce greenhouse gas emissions. In Ireland, peat soils cover ~1.46 million hectares (Connolly and Holden, 2009), storing ~2.3 billion tonnes of carbon (Renou-Wilson et al., 2022) the majority of which are drained for agriculture, forestry, horticulture, and energy production (Habib and Connolly, 2023). Ireland has set ambitious targets for reduction of greenhouse gas emissions via rewetting/restoration of peatlands (DECC, 2021). The Peatland Climate Action Scheme 2020 targets rewetting 33,000 hectares of Bord na Mona bogs and the DECC, 2021, targets 80,000 hectares of drained organic soil grassland by 2030. However, there is uncertainty in spatial extent (Xu et al., 2018, Connolly and Holden, 2009) and identification of peatlands which have been modified for agriculture, forestry, and following land use changes (Habib and Connolly, 2023).

At the global scale, peatland maps are created by combining the Harmonized World Soil Database (HSWD) with regional and nationally available soil maps (UNEP, 2022, Xu et al., 2018). A review paper by Minasny et al., (2019) outlines twelve national scale peat mapping attempts, ranging from traditional methods to modern soil mapping techniques. The inconsistent techniques used translates to global uncertainty of peatland extent (Xu et al., 2018). Additionally increases in peatland map resolutions are needed to include previously unmapped peat in national inventories (Connolly and Holden, 2009).

National scale geophysical surveys may provide the most accurate estimates of peatland area, with the radiometric method showing prominence (Airo et al., 2014). Surveys can be conducted by aircraft, allowing for consistent coverage of large areas. Traditionally these data were used for bedrock and sediment mapping (Martelet et al., 2006), but several local studies have investigated the potential of Radiometrics when considering peatland mapping (Ameglio, 2018; Beamish, 2014; Reinhardt and Herrmann, 2019; Siemon et al., 2020).

The Geological Survey, Ireland (GSI) Tellus Programme, (GSI, 2022) aims to gather high-resolution airborne magnetic, radiometric, and electromagnetic (EM) data over Ireland, along with a spatially distributed soil geochemical data. This provides a unique opportunity to map peatland extent nationally at a resolution of 50m. This task links directly to one of the principal goals of the GSI's research strategy 2016-2020 vision in providing reliable geoscience support for environmental protection and effective spatial planning.

O'Leary et al., (2022) integrated a supervised machine learning approach, with Tellus radiometric data to identify a soil as either peat or non-peat. Note, for this work "peat" means Organic Soils with no differentiation into Raised/Blanket bogs, Fens, Mires etc. Results also included previously unmapped peatland areas which were converted to forestry and agriculture.

The overall objective of this project was to expand the work of O'Leary et al., (2022). This included the production of a national peatland map, derived from all currently available Tellus airborne survey data. Validation of this map is performed with the GSI's Loss on Ignition (LOI) dataset, from within the Tellus soil Geochemical programme and additional ground truth data has been provided by other ongoing research projects.

(i) Results, scientific/engineering targets reached beyond the state of the art and conclusions

<u>Methodology</u>

All twelve currently available Tellus blocks (Figure 1) where downloaded. Each block contains elemental concentrations of Potassium (K), Uranium (U) & Thorium (Th) as well as a Total Count (TC) from the full energy spectrum. Each block's data were converted to Counts per Second (CPS) via sensitivity value for each block (See individual block processing reports) and gridded using Multilevel B-Spline interpolation to 50 m x 50 m grid cells. After the removal of exclusion zones (i.e., water bodies), a total of 22,085,597 grid cells are present (including overlap areas between blocks). All data are projected to Irish Transverse Mercator coordinate reference system.

Differences between each block and any acquisition parameter where examined. This was to ensure the influence of changing environmental conditions between block acquisition years is minimised. To apply the supervised machine learning of O'Leary et al. (2022), the Quaternary Geology Map (QGM) was simplified to a peat or non-peat classification at 50 x 50m pixels. This did not affect the resolution of the QGM but allowed for the extraction of discrete training points.

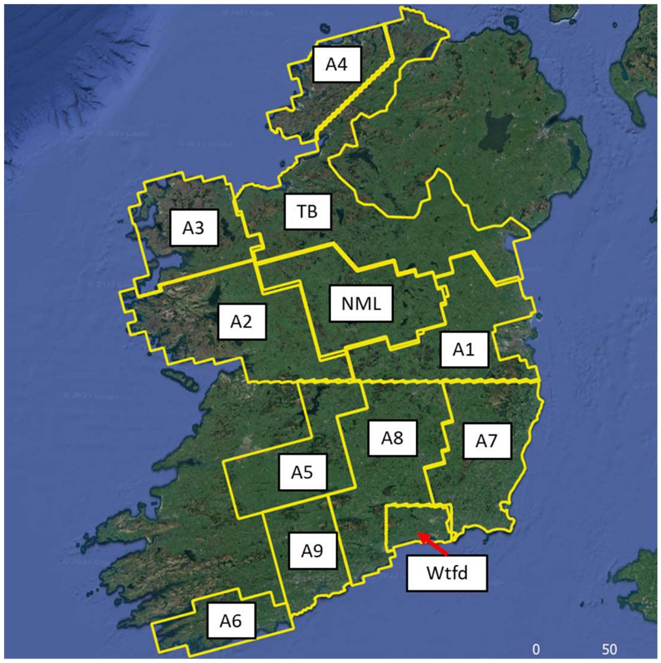

Figure 1: Map of Ireland with all Tellus Blocks outlined.

The 4 Tellus radiometric (K, U, Th & TC) data layers along with a Tellus derived Digital Elevation model (E) and its derived Slope (S) were used as predictors of the presence of a peat soil at each gridded pixel (Figure 2). The simplified QGM was used to identify areas of known peat or non-peat which acted as training locations within each block. Spatial rules were applied to these training data to ensure only valid training locations were chosen. This included a ±200 m buffer zone defined along the boundaries of Peat and Non-Peat classification in the QGM. No training data was selected from within this buffer zone. Training data was selected with random geographic sampling from within the remaining QGM Peat classification. The number of training points varied from block to block, depending on the area of peatland present in the QGM. The same number of training points was chosen from the QGM non-Peat classification within the same block. An average training success of 95.6 % was achieved across all blocks. A trained Neural Network was produced for each Block, indicating a robustly trained model.

The appropriate trained Neural Network was then applied to all data from within a single block. Each pixel was classified into either Peat or Non-Peat and a Neural Network confidence value is also output. This value relates to how confident the neural network's prediction i.e., a pixel could be classed as "Peat" with an 80 % confidence. A value of > 75 % indicates a High Confidence (HC) and a value between 50 – 75 % indicates a Low Confidence (LC). As this is a binary classification (Peat or Non-Peat) the confidence values are always > 50%. This confidence value allows for a 4 Class map to be produced with classifications of Peat (HC), Peat (LC), Non-Peat (LC), Non-Peat (HC).

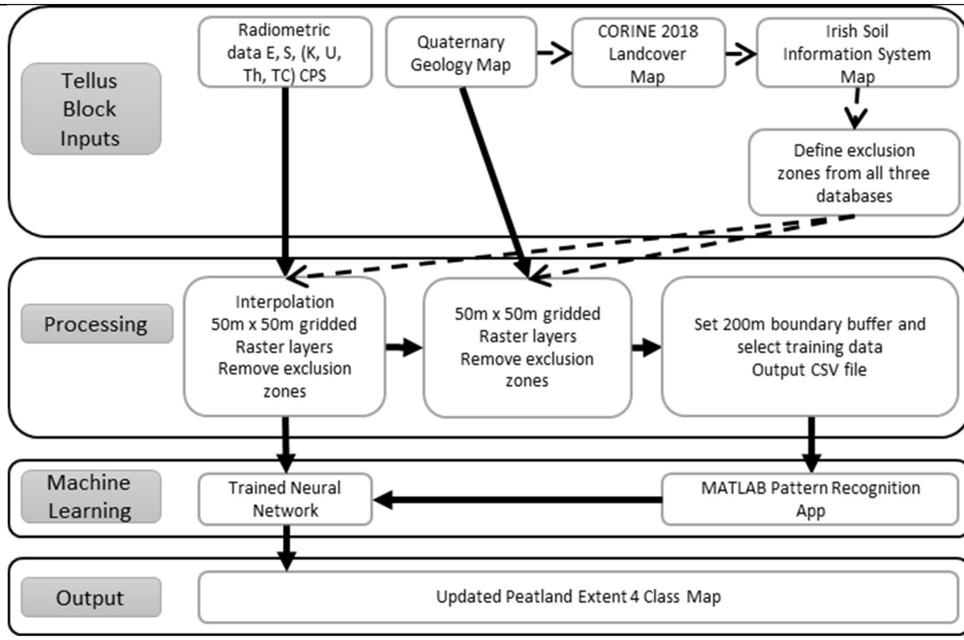

Figure 2: Method Flow Diagram (Updated from O'Leary et al. 2022)

There were two instances where blocks were merged during the Neural Network training, where A5 & A6 and Blocks A8 & A9 were treated as single blocks. This was necessary due to the low number of training points available in Blocks A6 and A9. However, these blocks were acquired during the same acquisition year (A5 & A6 in 2018/19, A8 & A9 in 2020/21), effectively allowing them to be treated as one block.

The final step was to merge the individual blocks into a single national 4 Class peatland map. This was achieved using simple IF/THEN logic in areas of overlap between blocks and an averaging of confidence values (See Supplementary Material for more information).

Validation

The national Tellus PeatMap (TPM) was validated by two means. Firstly, a quantitative assessment of prediction power of the 4-classification peatland map was conducted by utilising the Tellus ground Geochemistry LOI dataset. This consists of 8,695 sample locations across the northern half of Ireland (Figure 3). These validation points contain two LOI values, one for the shallow soil (20cm) and one for deep soil (50cm). A third average depth LOI value is also calculated as Radiometric data is considered a bulk reading to approx. 60 cm in soils (Beamish, 2013). In this work an LOI value of ≥ 30 % us considered a peat soil. As LOI data is not yet available in all areas where Radiometric data has been acquired, it is assumed that these results are representative for the full TPM.

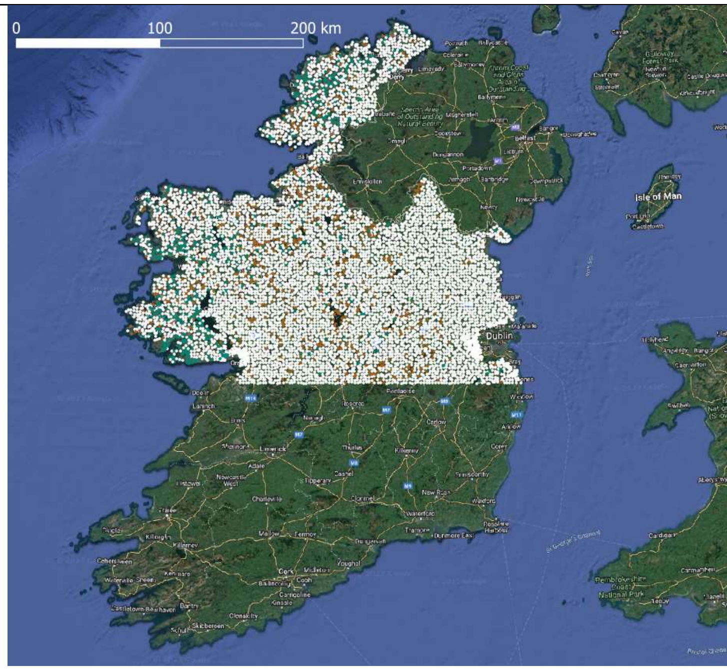

Figure 3: LOI data points available under current GSI data release

All 8,695 samples are compared to their associated 50 x 50 m pixel in the 4 Class TPM. The results can then be tabulated (Table 1). This table shows that the 4 Class TPM can be successfully compared to LOI ground truth data and that the classifications are mapping the transition zone between peat and non-peat soils. The final column shows the Neural Network confidence at these sample locations, showing that these confidence values are valid when used to create the 4 Class TPM.

Table 1: Quantitative validation of Tellus Peatmap with Tellus LOI data samples

		LOI %			
	Count	Shallow Average	Deep Average	Average Average	TPM Average Conf
Non- Peat HC	5795	10.3%	17.4%	13.9%	97 %
Non-Peat LC	484	30.0%	41.3%	35.7%	64 %
Peat LC	380	39.3%	52.0%	45.6%	63 %
Peat HC	2036	74.8%	80.0%	77.4%	95 %

The second validation of the TPM was a qualitative comparison with 12 field scale sites where peat soil is known to be present all of which are under grassland. These sites are part of the ReWET project in Teagasc. At each site peat thickness and extent has been mapped. An example of one of these sites is below (Figure 4).

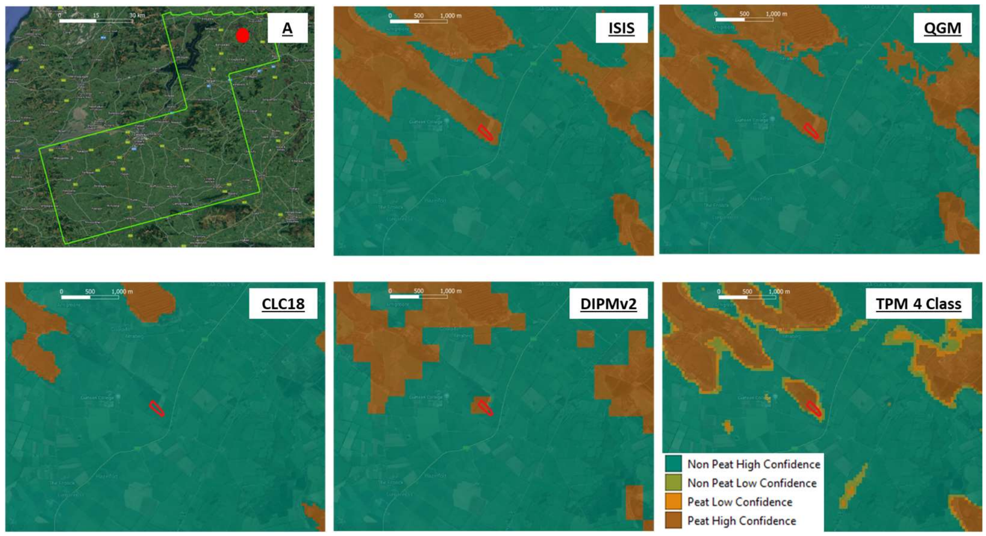

Figure 4: Qualitative comparison between TPM 4 Class and other national peatland databases on 2 ha site (red outline) located in Tellus Block A4 (A). Other national peatland databases include Irish Soil Information System (ISIS), Quaternary Geology Map (QGM), CORINE 2018 landcover map (CLC18), Derived Irish Peat Map v2 (DIPMv2)

This site has peat depths ranging from ~ 180 cm in the North-West of this field to ~ 40 cm in the South-East. This transition from deep to shallow is matched by the TPM 4 Class map showing a transition from Peat HC to Peat LC. More generally the increased resolution of the boundary between peat and non-peat soils can be observed in this figure. Also, the LC zones appear at the boundaries of the peat non peat areas and this is observed at all 12 ReWET sites.

Results and Conclusion

This map estimates the area of peatlands (within the current Tellus airborne acquisition of approx. 80 % of Ireland) to be 1.2 million ha (related to Peat HC & LC). This compares to other national databases within the same Tellus acquisition footprint (ISIS: 1.4 m ha, QGM: 1.1 m ha, CLC18: 1 m ha. DIPMv2: 1.2 m ha). It has a pixel resolution of 50 x 50 m and a model classification confidence of 93.5 %. The map is validated against 8,695 validation points which measure the LOI. The produced map agreed with these ground points 87.1%

The main advantage of using a dataset such as the Tellus Radiometric data is that firstly it is spatially consistent across the country which allows for increased resolution. This is particularly important when considering boundary between peat and non-peat soils. Secondly the radiometric data are a measurement of the subsurface of interest, therefore can represent the soil regardless of landcover, which is a limitation of any satellite-based soil mapping method.

However, it should be noted that no investigation into the division of radiometric data into specific peatland types has been performed. Therefore, the term “Peat” here relates to any peaty soil (LOI ≥ 30 %), with no differentiation of peatland type (i.e., Raised bog, Blanket Bog, Grass over peat, fen) possible.

These advantages result in a map can identify peat soils via direct measurement and can act as a stand-alone map, or can be integrated with traditional or satellite derived peat maps, which would allow for division of the TPM into type of peat (i.e., raised bog, blanket bog, fen etc). This would require further analysis.

The result of this short-call project is the production of a 4-Class TPM where Airborne Tellus Radiometric data are present (Figure 5), which highlights the presence of peat soils and the transition to non-peat soils via a Neural Network confidence value.

Validation of this map has been performed both quantitatively (Table 1) and qualitatively (Figure 4). However, a full national map and final validation cannot be performed until both Tellus Airborne and Ground surveys have been completed, this project presents a methodology which allows for a simple addition of blocks and validation data as and when they become available.

The method is robust, and this is the first time it has been used in a national context. Such a method has a global application, which is needed given the importance now attached to peatlands and the degree of uncertainty on global extent and implications for carbon stock and climate change mitigation opportunities.

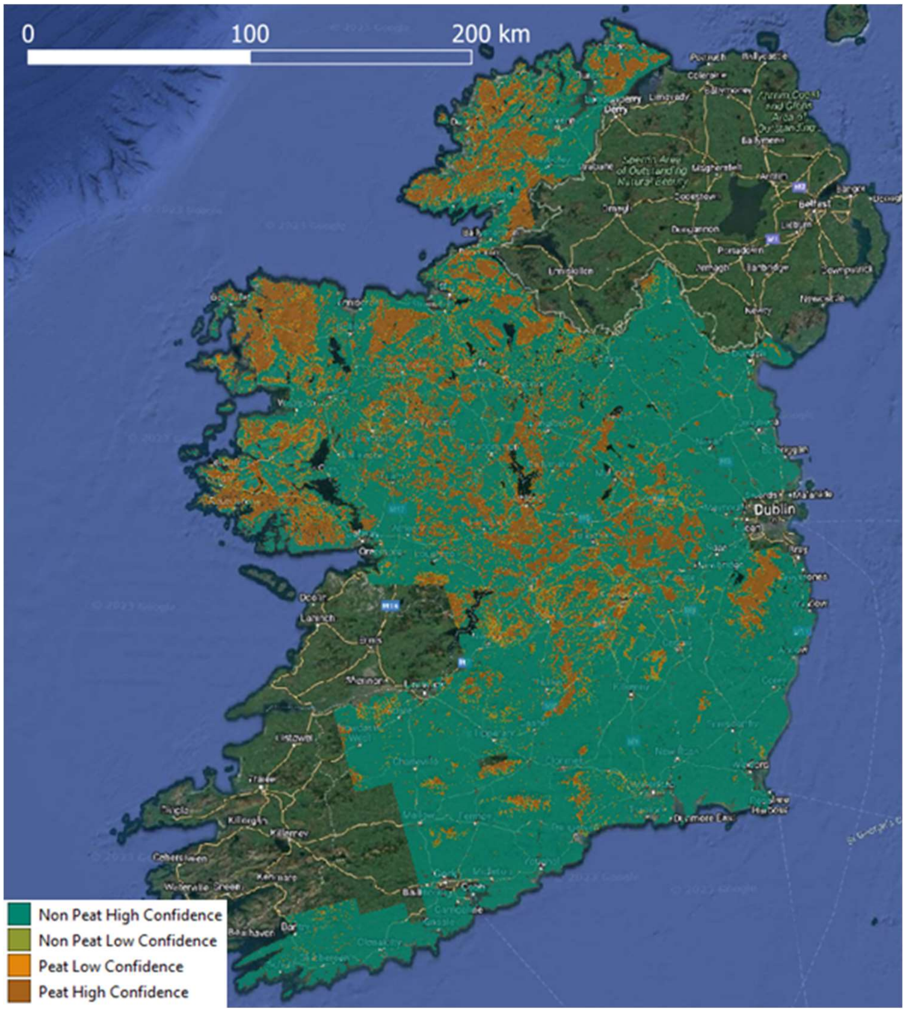

Figure 5: National Tellus Peatland 4 Class map

References:

Airo, M.-L., Hyvönen, E., Lerssi, J., Leväniemi, H., Ruotsalainen, A., 2014. Tips and tools for the application of GTK's airborne geophysical data, Geological Survey of Finland, https://tupa.gtk.fi/julkaisu/tutkimusraportti/tr_215.pdf, (accessed 09/05/2022)

Ameglio, L., 2018. Review of developments in airborne geophysics and geomatics to map variability of soil properties. 14th International Conference on Precision Agriculture, https://www.ispag.org/proceedings/?action=download&item=5024, (accessed 14/04/2022)

Beamish, D., 2014. Peat Mapping Associations of Airborne Radiometric Survey Data. Remote Sens-Basel 6(1), 521-539. https://doi.org/10.3390/rs6010521

Connolly, J., Holden, N.M., 2009. Mapping peat soils in Ireland: updating the derived Irish peat map. Irish Geography 42(3), 343-352. http://dx.doi.org/10.1080/00750770903407989

DECC, 2021. Climate Action Plan 2021, In Press, https://assets.gov.ie/224574/be2fecb2-2fb7-450e-9f5f-24204c9c9fbf.pdf, (accessed 23/06/2022)

GSI, 2022. Tellus Survey. https://www.gsi.ie/en-ie/programmes-and-projects/tellus/Pages/default.aspx, (accessed 01/05/2022)

Habib, W., Connolly, J., 2023. A national-scale assessment of land use change in peatlands between 1989 and 2020 using Landsat data and Google Earth Engine—a case study of Ireland. Regional Environmental Change 23(4), 124. https://doi.org/10.1007%2Fs10113-023-02116-0

IPCC, 2018. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)], In Press, https://www.ipcc.ch/sr15/download/, (accessed 23/06/2022)

Kreyling, J., Tanneberger, F., Jansen, F., van der Linden, S., Aggenbach, C., Bluml, V., Couwenberg, J., Emsens, W.J., Joosten, H., Klimkowska, A., Kotowski, W., Kozub, L., Lennartz, B., Liczner, Y., Liu, H., Michaelis, D., Oehmke, C., Parakenings, K., Pleyl, E., Poyda, A., Raabe, S., Rohl, M., Rucker, K., Schneider, A., Schrautzer, J., Schroder, C., Schug, F., Seeber, E., Thiel, F., Thiele, S., Tiemeyer, B., Timmermann, T., Urich, T., van

Diggelen, R., Vegelin, K., Verbruggen, E., Wilmking, M., Wrage-Monnig, N., Wolejko, L., Zak, D., Jurasinski, G., 2021. Rewetting does not return drained fen peatlands to their old selves. Nat Commun 12(1). https://doi.org/10.1038/s41467-021-25619-y

Martelet, G., Truffert, C., Tourliere, B., Ledru, P., Perrin, J., 2006. Classifying airborne radiometry data with Agglomerative Hierarchical Clustering: A tool for geological mapping in context of rainforest (French Guiana). International Journal of Applied Earth Observation and Geoinformation 8(3), 208-223. https://doi.org/10.1016/j.jag.2005.09.003

O'Leary, D., Brown, C., Daly, E., 2022. Digital soil mapping of peatland using airborne radiometric data and supervised machine learning – implication for the assessment of carbon stock. Geoderma 428. https://doi.org/10.1016/j.geoderma.2022.116086

Reinhardt, N., Herrmann, L., 2019. Gamma-ray spectrometry as versatile tool in soil science: A critical review. J Plant Nutr Soil Sc 182(1), 9-27. https://doi.org/10.1002/jpln.201700447

Renou-Wilson, F., Kenneth A. Byrne, Raymond Flynn, Alina Premrov, Emily Riondato, Matthew Saunders, Killian Walz, Wilson, D., 2022. Peatland Properties Influencing Greenhouse Gas Emissions and Removal, Environmental Protection Agency, https://www.epa.ie/publications/research/land-use-soils-and-transport/Research_Report_401.pdf, (accessed 27/06/2022)

Siemon, B., Ibs-von Seht, M., Frank, S., 2020. Airborne Electromagnetic and Radiometric Peat Thickness Mapping of a Bog in Northwest Germany (Ahlen-Falkenberger Moor). Remote Sens-Basel 12(2). https://doi.org/10.3390/rs12020203

UNEP, 2022. Global Peatlands Assessment – The State of the World's Peatlands: Evidence for action toward the conservation, restoration, and sustainable management of peatlands. Main Report., United Nations Environment Programme, Nairobi, https://wedocs.unep.org/bitstream/handle/20.500.11822/41222/peatland_assessment.pdf?sequence=1&isAllowed=y, (accessed 05/01/2023)

Xu, J.R., Morris, P.J., Liu, J.G., Holden, J., 2018. PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. Catena 160, 134-140. https://doi.org/10.1016/j.catena.2017.09.010

(ii) Project Implementation (milestones, deliverables, project management)

Aside from an alteration to the start date the project ran to schedule.

Gantt		National Peatland map using airborne Radiometric data							
		TASKS AT THE END OF THE MONTH INDICATED							
			1	2	3	4	5	6	7
TASKS	1	Download all data from Tellus data archive for all acquisition blocks							
	2	Document acquisition parameters for each block and establish differences							
	3	Convert all RM data to cps unit							
	4	Train neural network for each Tellus acquisition block							
	5	Create block by block peatland extent map							
	6	Assess block to block match between individual maps							
	7	Determine predictability between RM data and LOI for each block							
	8	Perform unsupervised clustering on each Block							
	9	Predict peatland SOC from clustering results							
	10	Create national level peatland map merged from all currently available blocks, including a layer of predicted SOC							
		MILESTONES AT THE START OF THE MONTH INDICATED							
MILESTONES	1	Create a consistently formated cps dataset for all acqisition blocks including relevant acquisition information							
	2	Mid term technical review and report completed							
	3	Training material created for NUIG geophysics module							
	4	Present at EGU annual meeting							
	5	Draft for article for high impact journal							
	6	Draft Final Report submitted							
		DELIVERABLES AT THE START OF THE MONTH INDICATED							
DELIVERABLES	1	Mid Term report							
	2	EGU Presenation Delivery							
	3	Maps and Data delivered to GSI							
	4	Training material delivered to NUIG geophysics module							
	5	Article submission for high impact journal							
	6	Final Report submitted and accepted							

(iii) Outputs to date

- EGU2023 Conference Presentation: "Using environmental radioactivity to create a national scale peatlands map: a case study from Ireland." O'Leary, D., Connolly, J., Gilet, L., Hodgson, J., Brown, C., Daly, E.

- ENVIRON2023: "Using Tellus Airborne Radiometric data to update the national peatland map in Ireland." O'Leary, D., Connolly, J., Gilet, L., Hodgson, J., Brown, C., Daly, E.

- Tellus Peatmap – Raster Map: Not yet published. To be made available on Tellus Online Data viewer as appropriate by GSI.

(iv) Impact

- Relevance/application to GSI programmes, where applicable
The new TPM can be used in assisting the updating of the GSI Quaternary Geology Map and could also aid in identifying sampling locations for any geochemical assessment of peatlands.

The TPM can also be integrated with landcover datasets, such as the CORINE 2018 or the EPA's National Landcover map, to update national estimates of various classes of peatland, i.e., Cutover peat, Pristine peat, Blanket Bog, Grassland on peat, Fens etc.

- Other impacts
1. University of Galway have been in contact with DAFM and EPA both of which have expressed interest in using the new Tellus Peat Map to help in the implementation of the proposed rewetting of drained organic agricultural soils. Knowledge of where peat soils are present is one of the first steps in identifying locations for rewetting and assessing impacts of any rewetting.
2. Integration of the TPM within the IPSM methodology to refine the extent of peat in Ireland.
3. As part of the single farm payment scheme and the proposed EU biodiversity law new management practices are required on grassland peat soils. A high-resolution peat map would be very useful from policy and implementation perspective.
4. The publication and availability of the TPM will internationalise the use of airborne Radiometric data for national peatland mapping, placing Ireland as world leaders in remote peatland mapping. Interest in these methods from Canadian and Danish colleagues have already been established, via a funded guest speaker role to Canada in February 2023 and an invitation for a research visit to Denmark, planned for early 2024.
5. Capacity building by developing the research skills of a PhD student into an independent researcher who is now a global leader in the understanding and integration of radiometric data and machine learning.
6. The expertise developed in this project have directly feed into and helped facilitated a Research proposal to DAFM in April 2023. Outcome pending.

Publications:

Planned publication to High Impact Journal (Remote Sensing of the Environment (IF: 13.5) or similar) to be submitted by Spring 2024

RTE Brainstorm article: https://www.rte.ie/brainstorm/2023/0403/1367931-ireland-peatland-bogs-measurement-survey/

Peatland News (Irish Peatland Conservation Counsil bi-annual publication): “Using Machine Learning for Peatland Mapping”. O’Leary, D. Spring 2023 edition.