The Peatland Challenge – Mission Impossible for the Forgotten Lands?

Richard Lindsay
University of East London, and
IUCN UK Peatland Programme

Introduction

Despite growing recognition that peatlands are important on the local, regional and global scale, peatlands within the EU continue to face a number of significant challenges, so in this talk I want to take you to the Eiffel Tower, explore the uttermost depths of the ocean, highlight the perils of the new normal, dive into the heart of the atom, review one of the biggest intelligence disasters of the 20th Century, discuss an identity crisis affecting the fundamental scientific method, delve into scientific incest, ask whether the universe has an ironic sense of humour, and I may even touch on peatlands.

Revealing the Oceans

Let's begin with the oceans. In December 1872, the *Challenger* Expedition set sail from Portsmouth, England, on the first oceanographic expedition of its kind to study and map the world's oceans in a systematic way. In its 4-year journey it sailed through every ocean except the Arctic Ocean, sampling and measuring. It produced the first bathymetric map of the world's oceans, but it was a map based on only 492 deep-sea soundings spread along its 68,890 nautical mile route, leaving much of the ocean floor still a speculative mystery.

It was not until the period of the Cold War in the 1960s that new maps of the ocean floor began to be generated using sonar in order to facilitate navigation of submarines armed with nuclear warheads. These maps not only laid bare the whole ocean floor but also, incidentally, provided the first solid evidence for continental drift (Vine and Matthews, 1968). It is often said that we know more about the surface of the moon than we know about the deep oceans of Earth, yet everyone with a smartphone or computer can now pull up a detailed map of the ocean floor using Google Maps or Google Earth (see Figure 1). Today, it would be more accurate to say that we know more about the surface of the Moon *and* of the ocean floor than we do about the world's peatlands.

Figure 1. The deep ocean floor as visible using Google Maps.

No equivalent map of the world's peatland depths exists. In terms of the world's peat depths, we are still in the era of the Challenger Expedition, relying on isolated cores and depth measurements from which we then attempt to create depth maps similar to, and as speculative as, that produced by the Challenger Expedition. Ground penetrating radar has been used in some areas with some success, as has electrical resistivity and induced polarisation imaging, but almost always for relatively small areas or small sub-catchments (e.g. Comas et al., 2011; Loisel et al, 2013; Katona et al., 2021). Furthermore, such methods and equipment do not lend themselves to much of the terrain, water table, vegetation and microtpography commonly associated with peatlands around the world.

And at least the Challenger Expedition knew where the oceans were, which is more than can be said for peatlands researchers and their peatlands today. We are still discovering areas of peatland the size of entire countries which have previously been overlooked and described as some other habitat (Lähteenoja et al., 2009; Dargie et al., 2017). Meanwhile argument continues to rage about what criteria should be used to define a 'peatland' (Lourenco, Fitchett & Woodborne, 2022) – is it 50 cm depth? Or 40 cm? Or 1 m? Or perhaps 30 cm? Or alternatively 30 % organic content? (Joosten et al., 2017a) Or perhaps 20 %? Or 10%...? (FAO, 2015) Depth thresholds such as 1 m, 50 cm or 40 cm have generally been derived for surveys driven by the objective of peatland exploitation, whether this be sufficient depth for peat extraction, sufficiently shallow for agricultural land claim or so deep that engineering construction would face significant challenges (Hallet & Deeks, 2012; Lilly et al., 2015). The ecosystem benefits of peatlands are now increasingly recognised as extending well beyond goods and services obtained by their unsustainable exploitation, and the thing that distinguishes peat from other soils is not depth but instead its extraordinary and persistent carbon content combined with a moisture content so high that oxidative decomposition is prevented.

To emphasise the extraordinary nature of this carbon store, it is possible to compare the carbon content per unit area of grasslands, oakwoods, tropical forests, and typical peat depths (see Figure 2).

It can be seen that the calculated average peat depth for Scotland of 1.34 m holds more than twice the carbon per hectare stored in deciduous or tropical forests, while a peat thickness of only 30 cm, typically forming extensive margins of deeper peat deposits, can contain as much carbon as a tropical forest. In the UK alone, if archaic, exploitation-focused depth thresholds are employed to define what is 'peat', the resulting exclusion of shallower peats from the national peatland inventory reduces the area of UK peatland from more than 7 million hectares to only 3 million hectares. This has major possible implications for both natural capital and Nationally Determined Contributions (NDCs). If such areas are excluded as 'peat', they are likely to be regarded as, and therefore managed as, some other habitat, usually to the severe detriment of their peatland ecosystem character and services including loss of their carbon store as substantial emissions to the atmosphere. How we define peat is thus a major challenge not merely for the EU but for every nation on Earth.

Within the last five years or so, however, there has been some encouraging progress in terms of both mapping of peat and estimating peat depths over wide areas. The *magnum opus* "Mires and Peatlands of Europe" (Joosten et al., 2017b) has provided the first comprehensive collation of what is currently known about Europe's peatlands, from which the latest map of European peatlands has been derived. This huge assemblage of information is nonetheless constrained by the differing approaches to the mapping of peatlands adopted by each contributing nation, and is not available as an open-access resource.

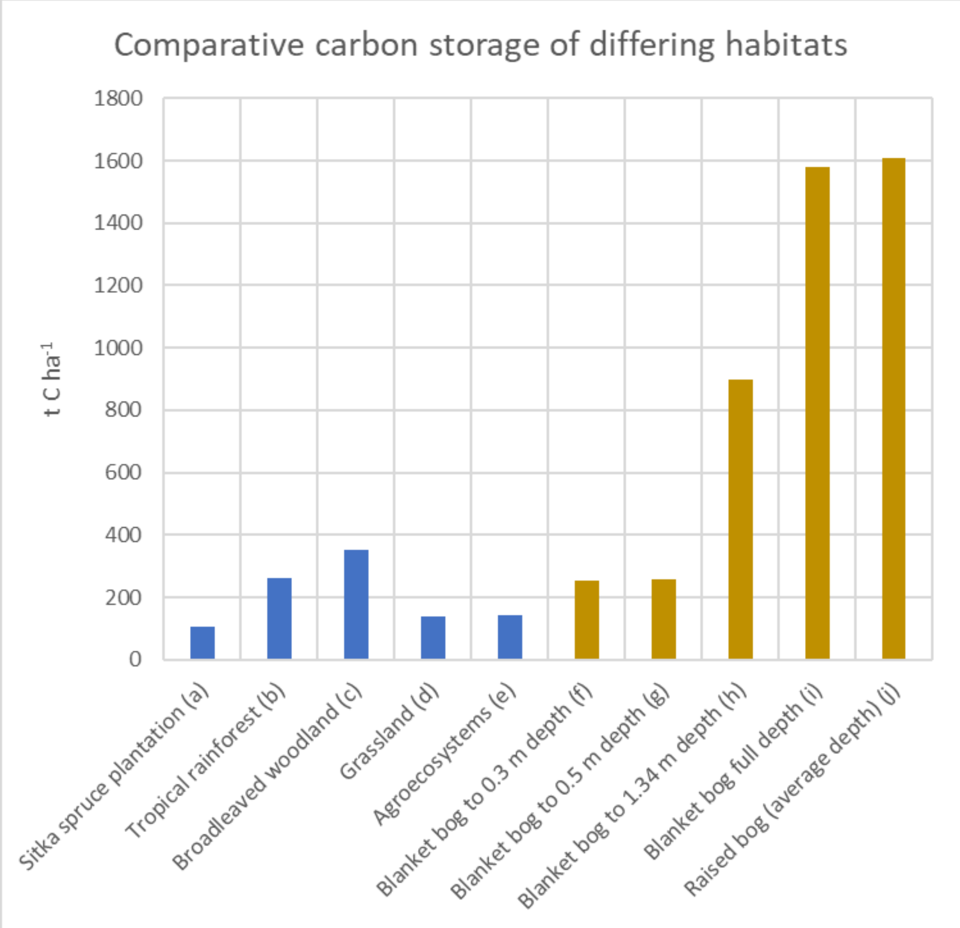

Figure 2. Quantity of stored carbon per unit area (hectare) in various ecosystems. Data from (a) Morison et al. (2012) for 80-year rotation, for C *added* by plantation to existing soil carbon stock; (b) Sullivan et al. (2017) with % soil C added based on Blais et al. (2005); (c, g, i, j) Gregg et al. (2021); (d) White et al. (2000); (f) Crouch and Chandler (2021); (h) Smith,et al. (2009).

The Global Peatland Database, a project of the International Mire Conservation Group and managed by the Greifswald Mire Centre has been developing multi-factoral methods for identifying likely areas of peatland around the world. From this, a first-stage Global Peatland Map has been produced. However, neither the database nor the map are available as an open interactive resource, meaning that it more closely resembles the 50 volumes of the Challenger Expedition published between 1876 and 1895 and held in the Library of the Royal Society than the ocean maps available through Google Maps today.

The multi-factoral approach of the Global Peatland Database may in future also be assisted by the nature of the atomic nucleus. This is because all bedrock emits some radioactivity from atomic nuclei, but the resulting gamma radiation is attenuated by any overburden soils. Peat attenuates this radiation in a highly distinctive way, offering the potential to use airborne or satellite-based radiometry to map both the extent and depth of peat (Silvestre et al., 2019; O'Leary, Brown and Daley, 2022). This approach is in its early proving stages and will still require ground-truth and ground-based data such as dry bulk density to calculate carbon contents, but it may offer a window into the world's peatlands in much the same way that sonar mapping opened a window on the world's oceans.

The mapping of peat soils also highlights another issue of particular relevance to the principle of Favourable Conservation Status (FCS) although also has much wider relevance, namely the danger posed by the 'new normal'. A key part of the definition of FCS is that 'the natural range of the interest be stable or increasing', but often the natural range of a habitat is obscured by habitat loss. Thus, in the UK we have evidence of former raised bogs as far south as the south coast of England, but as a result of extensive habitat loss the perceived 'new normal' distribution of raised bogs in Britain is that raised bogs only occur in the north and west of the country (Lindsay & Immirzi, 1996). A similar story can be found in many other nations both in the EU and elsewhere (e.g. Joosten et al., 2017b). Accepting the 'new normal' as equivalent to the 'natural range' permanently closes off options for restoration of the true natural range. It is therefore vital that such perceived equivalence is resisted and that opportunities for range recovery are left open, even encouraged.

My first challenge for the European Union is thus to encourage development of and support for the systematic mapping of peatland extent and depth both within the EU and across the globe, and to make the ongoing results available as an open-access resource for all to use as readily as the world's oceans are now open to all through Google Maps and Google Earth.

My second challenge is that the concept of 'natural range' is highlighted, encouraged and promoted as a guiding principle for peatland restoration works where the opportunity presents itself.

Intelligence

Pearl Harbor, December 7th 1941, is still regarded within the intelligence community as the worst intelligence failing in US history. The failure arose not because there was insufficient information to provide a warning – ample evidence was available, but the failure lay in the assembly, collation and, most crucially, the assessment, interpretation and dissemination of the available evidence.

The work of intelligence is based on a well-established 'Intelligence Cycle' (Hughes-Wilson, 2016). This cycle consists of:

- Direction: where a need for information is specified by a decision-maker(s);
- Collection: in which information is obtained using a formal *collection plan*;
- Collation: where the information is brought together into a centralised, readily-accessible database of some form and assessed for quality and reliability;
- Interpretation: where the information is analysed, interpreted and turned into intelligence by an intelligence analyst based typically on questions such as: *What is it? What is it doing? What does it mean?*
- Dissemination: the derived intelligence is transmitted to the decision-maker and others who need to know in a format that is as clear and unambiguous as possible.

The decision-maker(s) may then require further information based on what has been provided, and so the cycle begins again.

In the case of peatlands, as with Pearl Harbor, the failures also lie in collation, interpretation and dissemination. A brief search through Google Scholar is enough to convince anyone of the huge amount of information now being published about peatlands. After languishing for many decades in the shadows, peatlands have begun attracting substantial sums of research and site-management funding, largely, it has to be recognised, because of their huge stores of carbon. While this outpouring of funds has led to an equal outpouring of data, much less attention has been focused on the proper and effective (in the intelligence sense) collation, interpretation and dissemination of these data.

The academic publishing world is based on review of every submitted manuscript, a task usually undertaken by a small number of academic peers. Any given academic journal will have a particular theme or focus – e.g. geomorphology, ecology, hydrology – and it is therefore inevitable that the editorial team and the peer-reviewers called on to review a manuscript will tend to have expertise in that particular theme. The formal 'scientific method', however, requires that the experimental object first be accurately described. In the case of peatlands (indeed any ecosystem) this presents a challenge because the ecosystem represents a complex dynamic entity which has a present face but also a past history and this past history may be having a major influence on the present face. An accurate description of an experimental peatland object may therefore require a deep dive into the site's history and possible consequences of this for the present state and ongoing dynamics of the system. This is something which rarely features in academic peatland publications despite the fact that peatlands almost uniquely store a record of their past history within the peat in a way that does not occur in a forest or a grassland.

Furthermore, the themed focus of individual academic journals often means that peer review focuses on only those aspects of the research which relate to that theme while other aspects of the manuscript are not subject to scrutiny. Thus, for example, an atmospheric science journal may receive a manuscript from an atmospheric science team who have worked on a peatland. The manuscript is sent for peer-review to three atmospheric scientists who thoroughly approve of the methods employed and the interpretation of the atmospheric science data. The editor then publishes the paper. At no point has there been any critical assessment of the description provided by the authors of the experimental object itself. In intelligence terms, this is a serious failure of information assessment during the Collation phase. A critical part of both the Collation and Interpretation phases of the intelligence cycle is an assessment of the information source – in this case, the peatland ecosystem. If the source is poorly defined or mis-identified, the reliability of the resulting information is ambiguous and must remain suspect until further investigation has produced more information about the source. The problem lies in the often-incestuous nature of the academic peer-review process – incestuous in the sense that peer review will often not stray beyond the confines of the main journal theme to ensure that the experimental object is accurately described.

A simple exercise will illustrate the problem. Take almost any academic peatland paper which does not focus primarily on the ecology of the system. Note the detail provided about the methods employed in relation to the theme of the journal or paper and compare this with the detail provided about the experimental object itself – i.e. the peatland ecosystem. A second exercise provides a further illustration. Search for any academic paper which uses the terms 'undisturbed', 'pristine' or 'natural' when describing an experimental peatland. Using the satellite view of Google Maps look carefully, zooming in to the finest detail, for any signs of disturbance – e.g. drains, blocks of forestry, roads, railway lines – within the evident expanse of the peat body. It is remarkable, and depressing, how often such signs are evident in supposedly 'undisturbed' sites – and use of such terms inevitably distorts the process of intelligence Interpretation.

This problem in academic publishing also highlights what has increasingly been described as the 'identity crisis' by ecologists and wildlife organisations. The number of people who can accurately identify species and indeed habitat features is steadily diminishing, making it ever-harder for research teams to include expertise responsible for ensuring that the experimental object is accurately described. The demise of more traditional taxonomic degree courses and those degrees focusing on what is increasingly disparaged as 'natural history' (i.e. field ecology), means that graduates with the necessary skills are an increasingly rare species. Furthermore, the relentless pressure on academics from universities, research funding bodies and journal editors to be publishing 'cutting-edge' research, when combined with the so-called identity crisis, means that descriptive ecology is increasingly hard to undertake, fund and publish, leading to repeated failures in Collection, Collation and Interpretation of 'intelligence'.

Another failing of the academic publishing world, when viewed through the lens of Intelligence, is that the whole process of Collection, Collation, Interpretation and Dissemination is un-coordinated. This, more than anything, is what led to the intelligence disaster of Pearl Harbor. Many parts of the intelligence community possessed key information but there was no overall coordination, collation or interpretation of this information. Similarly, individual academic papers are their own mini-process of collection, coordination and interpretation in the sense that each paper normally begins with a brief review of what is already known, but every paper stands as an isolated intelligence entity. Granted, there are occasional Review papers which bring together a mass of valuable information and interpret this – a classic example of Collection, Collation and Interpretation – but these review papers are *ad-hoc*, dependent upon individual enthusiasms as well as the willingness of journal editors to devote significant space to such items.

The final step of the Intelligence Cycle – namely Dissemination - is alas often absent from the academic publishing process. It is generally believed that publication in an academic journal *is* Dissemination, but the increasingly specialised and often arcane language used in academic publications, serve to make such documents accessible only to other specialists, often only specialists in that particular field. This is akin to the medical profession of the 18^{th} Century speaking only in Latin, in part to preserve the aura of expert knowledge and impress the patient. Policy-makers, politicians, decision-makers and practitioners are usually not in a position to interpret, nor assess critically, the complex detail of many academic papers. For example, it is a telling point just how few academic papers are directly referred to by peatland conservation practitioners when setting out their plans or describing what they have done, despite the plethora of published academic papers relevant to their activities. The Dissemination process for academic intelligence tends to remain within the academic community rather than, as the Intelligence Cycle requires, focusing on dissemination to the end-users of this intelligence – the policy makers, politicians and practitioners.

In many nations, the Intelligence Cycle falls to the statutory environmental agency, but some nations have no such identifiable agency and even in those nations which do possess a relevant agency, such agencies are often under-funded and under-staffed, meaning that capacity issues prevent effective deployment of the Intelligence Cycle. In the UK, the IUCN UK Peatland Programme has, in effect, identified the Intelligence Cycle as a key role for the Programme and has thus produced a series of Briefing Notes, Position Statements, instructional videos and other materials which seek to fill this gap, but with the UK no longer part of the EU thanks (no thanks) to Brexit, it is not clear who or what should bear the responsibility for the peatland Intelligence Cycle within Europe.

The European Union may have limited power in bringing pressure to bear on the academic publishing world and the design of academic courses, but **my third challenge to the EU would therefore be:**

- **to ensure that all EU-funded peatland-related research programmes require:**
    - **site descriptions to include investigations into the site history and thus possible underlying trajectory;**
    - **ecological expertise capable of providing an appropriate description of the peatland(s) under investigation;**
    - **critical assessment of existing published papers relevant to, and referred to by, the funded study;**
- **to encourage every EU member to establish an equivalent programme to the IUCN UK Peatland Programme;**

- **to ensure that there is a clear over-arching 'Intelligence Analyst' process for managing the peatland Intelligence Cycle within the EU.**

Time

Something at the base of the Eiffel Tower is a riddle that cannot be opened until 2113. Antti Ilvessuo from Finland created this riddle (a legend within the gaming world) as part of the video game Trials Evolution. He deliberately set the date far beyond the lifetime of himself and all other present-day gamers as a way of encouraging people to think beyond their lifetimes (Kotaku website; Sideways, BBC, 23 November 2022). Every time we carry out an act of peatland restoration we are doing the same thing, because the final result of our actions will never be revealed during our lifetimes.

Unfortunately, the funders of peatland restoration work rarely embrace the philosophy of Antti Ilvessuo, nor indeed does the modern academic world. Funders require evidence that their funding has achieved required outcomes, usually within the time-frame of the funding cycle which is typically no more than (and often much less than) five years. Funded research programmes are generally forced to operate within similar time constraints, and typical PhD studies even less, with the added pressure on academics to be regularly publishing as part of their annual performance review.

This unfortunate combination of circumstances has led to increasingly perverse outcomes in which restoration actions are undertaken specifically in order to be able to demonstrate an outcome to a funder when in fact other, less time-constrained actions may have been more appropriate. Meanwhile within the academic world, the number of papers which describe responses to interventions which occur within the first four or five years (or even the first four or five months) of an intervention are becoming increasingly common, even though the peatland ecosystem is quite evidently in a state of transition and ecological turmoil as a result of the intervention. Responses ten or twenty years after an intervention may well be very different from those observed two years after the intervention, but pressure to show results and pressure to publish mean that there is a heavy bias towards results which simply describe the peatland ecosystem in a state of change rather than on a steady post-intervention trajectory. It is hard to imagine such expectations being placed on a forest regeneration scheme, yet peatlands operate on timescales at least as long as those typical of forests.

Time. Time is the key that is so often forgotten or omitted where peatlands are concerned. We need to recognise the truth behind Antti Ilvessuo's action and accept that time is as important a tool in the restoration and description of peatland ecosystems as it is for oak or ash woodlands. Some peatland responses can be surprisingly rapid, but to treat all responses as equally rapid simply leads to perverse interpretations and perverse outcomes.

My fourth challenge to the EU is therefore that:

- **funding for peatland conservation actions to provide for maximum monitoring timescales;**
- **required outcomes to be actions putting in place those elements which will enable and encourage the system to follow a natural trajectory of recovery, rather than requiring evidence of such recovery within the funding time-frame;**
- **publications arising from restoration or research funding be clearly highlighted as describing systems in transition, unless the publication is describing impacts from actions undertaken at least a decade or more in the past;**
- **restoration teams be encouraged to recognise that time is an important part of their tool-kit and not to seek, or feel pressure to produce, instant results.**

The perverse universe

There is a perverse irony in the fact that the most carbon-rich habitat – namely peatland – also offers some of the most favoured locations for the construction of windfarms, which then requires significant damage to the peatland carbon store in order to build the infrastructure required to reduce our carbon emissions (Lindsay, 2016).

The reasons for this unfortunate overlap of interests are complex, involving meteorology, peatland dynamics, socio-economic interests, electricity-grid management and international government commitments. Reducing these to the most straightforward aspects of the issue, however, reveals three key truths:

- peatlands are cheap land;
- gentle hill slopes in oceanic climates favour peat formation;
- gentle hill slopes in oceanic climates offer low construction costs and high wind energies.

Throughout the EU and beyond, wherever there are blanket mires there is also pressure to build windfarms. Indeed it is not just blanket mire and it is not just windfarms. If some infrastructure must be built to traverse a landscape, it is all-too-frequently the peatland elements within that landscape which are targeted to form part of the route because peatlands are cheap compared to almost all other forms of land cover. In nations such as Spain, it is no exaggeration to say that the small expanses of blanket bog which occur in the northern mountains of that nation have been ravaged by the construction of windfarms along so many of the peat-draped mountain ridges (Fraga et al., 2008) – see Figure 3.

Figure 3. Windfarms constructed across the blanket mire landscapes of the Xistral Mountains, Spain.

Any such infrastructure traversing a peatland system will cut directly across the hydrology of the system unless it is raised above the system on piles – not a popular infrastructure choice because of the cost. The resulting destabilization of the hydrology and indeed the peat mass itself has led to several major instances of bog slides in Ireland and some lesser and less-reported examples elsewhere, with one celebrated case at Derrybrien, County Galway (Lindsay & Bragg, 2004), actually leading to deconstruction and removal of what was then the largest windfarm in Ireland (Irish Times website).

Given the current climate emergency, there is a clear and urgent need to maximise the transition from fossil fuels to renewable energy sources. If windfarms are not to be built on these high mountain ridges, bringing them down the hill then brings them into closer contact with resident communities which can lead to major socio-economic challenges resulting from turbine noise and loss of property value. Placing tall turbines within large expanses of forest with blades raised above the canopy is not desirable because the tree canopy gives rise to turbulence and consequent reduction in turbine efficiency, while the impacts on local canopy meteorology are likely to be significant and the potential impact on forest biodiversity – particularly birds and bats – may be substantial.

Where, then, to put these on-shore wind turbines? That, ultimately, must be a socio-economic and political decision, but what is important for the EU is that it recognises the inherent bias which puts peatlands at a disadvantage compared to other areas when such decisions are made. Peatlands continue to be considered as low-value land, areas that can only acquire value through damage or destruction of their inherent peatland character. Land value, meanwhile, is determined by many factors but in the rural environment, particularly in less-favoured areas within the rural environment, one of the chief factors is the level of central agricultural support. As support systems move more towards rewarding production and maintenance of ecosystem services, the potential for peatlands is considerable, given their immense carbon stores, their impact on water supply, their capacity for flood relief, their highly distinctive biodiversity, and their unparalleled environmental and archaeological archive.

In the UK, the UK Government Office for National Statistics has estimated that peatland ecosystem services are worth £888 million to the water industry in 2016, while restoration of just 55% of UK's damaged peatlands would be worth between £45 billion to £51 billion in terms of climate change emission alone (UK Office for National Statistics, 2019). The numbers are starting to add up. Peatlands do not need to be the forgotten lands of Europe.

My final challenge for the EU is therefore to recognise the economic bias that currently plays consistently against peatland ecosystems compared with other land-cover types, to pursue true socio-economic valuation of Europe's peatland systems and to create an economic framework in which peatlands are no longer the forgotten lands but are able at least to stand alongside the other elements of Europe's landscape on an equal footing.

References

Comas, X., Terry, N., Slater, L., Warren, M., Kolka, R., Kristiyono, A., Sudiana, N., Nurjaman, D. & Darusman, T. (2015) Imaging tropical peatlands in Indonesia using ground-penetrating radar (GPR) and electrical resistivity imaging (ERI): implications for carbon stock estimates and peat soil characterization. *Biogeosciences*, 12, 2995–3007.

Dargie, G.C., Lewis, S.L., Lawson, I.T., Mitchard, E.T.A., Page, S.E., Bocko, Y.E. & Ifo, S.A. (2017) Age, extent and carbon storage of the central Congo Basin peatland complex. *Nature*, 542, 86–90.

FAO - Food and Agriculture Organization of the United Nations. (2015) *World Reference Base for Soil Resources 2014 - International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. Update 2015. World Soil Resources Reports 106*. Rome: Food and Agriculture Organisation of the United Nations.

Fraga, M.I., Romero-Pedreira, D., Souto, M., Castro, D. and Sahuquillo, E. (2008) Assessing the impact of wind farms on the plant diversity. *Mires and Peat*, 4, Article 06.

of blanket bogs in the Xistral Mountains (NW Spain)

Hallet, S. and Deeks, L. (2012) A history of Soil Survey in England and Wales. *Geophysical Research Abstracts*, 14, EGU2012-5525.

Hughes-Wilson, J. (2016) *On Intelligence – The History of Espionage and the Secret World*. London: Constable, 510 pp.

Irish Times website: https://www.irishtimes.com/business/energy-and-resources/esb-to-decommission-derrybrien-wind-farm-s-70-turbines-1.4828766
Accessed 10th June 2023

Joosten, H., Couwenberg, J., Moen, A. & Tanneberger, F. (2017a) Mire and peatland terms and definitions in Europe. In: H. Joosten, F. Tanneberger & A. Moen (eds) *Mires and Peatlands of Europe – Status, Distribution and Conservation*. Schweitzerbart Science Publishers, Stuttgart, 65–96.

Joosten, H., Tanneberger, F. & Moen, A. (eds) (2017b) *Mires and Peatlands of Europe – Status, Distribution and Conservation*. Stuttgart: Schweitzerbart Science Publishers, 780 pp.

Katona, T., Gilfedder, B.S., Frei, S., Bücker, M. & Flores-Orozco, A. (2021) High-resolution induced polarization imaging of biogeochemical carbon turnover hotspots in a peatland. *Biogeosciences*, 18, 4039–4058.

Kotaku website: https://www.kotaku.com.au/2017/04/the-trials-evolution-riddle-has-been-solved-and-it-is-truly-unbelievable/
Accessed 10th June 2023

Lähteenoja, O., Ruokolainen, K., Schulman, L. & Oinonen, M. (2009) Amazonian peatlands: an ignored C sink and potential source. *Global Change Biology*, 15(9), 2311–2320.

Lilly, A., Miller, D., Towers, W., Donnelly, D., Poggio, L. and Carnegie, P. (2015) Mapping Scotland's Soil Resources. *Society of Cartographers Bulletin*, 48, 35–46.

Lindsay, R. 2016. Peatlands and Windfarms: Conflicting Carbon Targets and Environmental Impacts. in: Finlayson, C. Max, Milton, G. Randy, Prentice, R. Crawford and Davidson, Nick C. (ed.) *The Wetland Book: II: Distribution, Description and Conservation*. Dordrecht: Springer, 1-13. https://doi.org/10.1007/978-94-007-6173-5_50-1

Lindsay, R.A. and Bragg, O.M. (2004) *Wind Farms and Blanket Peat – The bog slide of 16th October 2003 at Derrybrien, Co. Galway, Ireland*. (Contract report for Derrybrien Residents' Co-operative.) Stratford, UK : University of East London. https://repository.uel.ac.uk/item/867x7

Lindsay, R.A. and Immirzi, C.P. (1996) *An inventory of lowland raised bogs in Great Britain. Scottish Natural Heritage Research, Survey and Monitoring Report. No. 78.* Perth : Scottish Natural Heritage.

Loisel, J., Yu, Z., Parsekian, A., Nolan, J. and Slater, L. (2013) Quantifying landscape morphology influence on peatland lateral expansion using ground-penetrating radar (GPR) and peat core analysis. *Journal of Geophysical Research: Biogeosciences*, 118(2), 373-384.

Lourenco, M., Fitchett, J.M. and Woodborne, S. (2022) Peat definitions: A critical review. *Progress in Physical Geography: Earth and Environment*, p.03091333221118353.

O'Leary, D., Brown, C. & Daley, E. (2022) Digital soil mapping of peatland using airborne radiometric data and supervised machine learning – Implication for the assessment of carbon stock. *Geoderma*, 428, 116086. https://doi.org/10.1016/j.geoderma.2022.116086

Silvestri, S., Christensen, C. W., Lysdahl, A. O. K., Anschütz, H., Pfaffhuber, A. A., & Viezzoli, A. (2019) Peatland volume mapping over resistive substrates with airborne electromagnetic technology. *Geophysical Research Letters*, 46, 6459–6468. https://doi.org/10.1029/2019GL083025

Sideways podcast – The Riddle: https://www.bbc.co.uk/programmes/m001fcsp Accessed: 10th June 2023

UK Office for National Statistics (2019) *Statistical Bulletin - UK natural capital: peatlands*. London: UK Government. https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalforpeatlands/naturalcapitalaccounts#:~:text=Peatlands%20occupy%20around%2012%25%20of,ecosystem%20services%20in%20the%20UK.

Vine, F. J. & Matthews, D. H. (1963) Magnetic anomalies over oceanic ridges. *Nature*, 199, 947– 949.