



Case Study

# Developing peatland ecosystem accounts to guide targets for restoration

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## Abstract

The United Nations System of Environmental and Economic Accounting - Ecosystem Accounting (SEEA EA) is a geospatial approach, whereby existing data on ecosystem stocks and flows are collated to show changes over time. The framework has been proposed as a means to track and monitor ecosystem restoration targets across the EU. Condition is a key consideration in the conservation assessment of habitats protected under the EU Habitats Directive and ecosystem condition accounts are also integral to the SEEA EA. While SEEA EA accounts have been developed at EU level for an array of ecosystem types, condition accounts remain the least developed. Collating available datasets under the SEEA EA framework, we developed extent and rudimentary condition accounts for peatland ecosystems at catchment scale in Ireland. Information relating to peatland ecosystem sub-types or habitat types was collated for peatland habitats listed under Annex I of the EU Habitats Directive, as well as degraded peatlands not included in EU nature conservation networks. While data relating to peatland condition were limited, understanding changes in ecosystem extent and incorporating knowledge of habitat types and degradation served as a proxy for ecosystem condition in the absence of more

comprehensive data. This highlighted the importance of the ecosystem extent account, which underpins all other accounts in the SEEA EA framework. Reflecting findings at EU level, drainage, disturbance and land conversion were identified as the main pressures affecting peatland condition. We highlighted a number of options to gather data to build more robust, time-series extent and condition accounts for peatlands at varying accounting scales. Overall, despite the absence of comprehensive data, bringing information under the SEEA EA framework is considered a good starting point, with the integration of expert ecological opinion considered essential to ensure development of reliable accounts, particularly when working at ecosystem sub-type (habitat type) and catchment scale.

## Keywords

peatlands, ecosystem accounting, condition account, reference condition, restoration.

## Ecosystem accounting to support restoration

Ecosystem loss and ongoing degradation is a global issue and widespread measures are required to reverse these trends (Díaz et al. 2019, Dasgupta 2021), particularly in the light of potential impacts of global climate change (IPCC 2021). Natural capital accounting is one of the emerging tools to better integrate biodiversity and climate considerations into public and business decision-making at all levels (Bateman and Mace 2020, Hein et al. 2020a, UNSD 2021). Incorporating approaches to the assessment of ecosystem stocks (their extent and condition) and the resultant effects on ecosystem flows (services and benefits), natural capital accounting presents a means to record and track changes over time through the development of time-series accounts, thereby increasing awareness of nature's contributions to human well-being (Obst 2015, Hein et al. 2020). The phrase "natural capital" refers to the stock of renewable and non-renewable natural resources that combine to yield a flow of benefits to people as per the definition by the [Capitals Coalition](#). In development since the 1990s and led mainly by accounting and statistical communities, Corporate Natural Capital Accounting approaches are mainly used by businesses, taking a microeconomic perspective (Whitaker 2019), while the United Nations System of Environmental Economic Accounting-Ecosystem Accounting (SEEA EA) is increasingly used by public and private bodies, taking a macroeconomic perspective (UNSD 2021). The SEEA EA was adopted as a statistical standard in 2021 and comprises a geospatial approach, whereby existing data on ecosystem stocks and flows are collated to show changes over time (Obst 2015, Eigenraam and Obst 2018, UNSD 2021). Designed since inception to align with the System of National Accounts (SNA), the SEEA EA can be applied at national scale (Eigenraam and Obst 2018), but can equally be used at smaller spatial scales (Farrell et al. 2021b). Developed in the EU context through the [MAES](#), [MAIA](#) and [INCA](#) projects, the SEEA EA has been identified as a key tool to deliver on the EU Strategy for Biodiversity 2030, particularly in relation to monitoring outcomes of the EU nature restoration plan where legally binding targets will be set for each EU Member State, requiring a scientific basis to establish realisable restoration targets (Vysna 2021).

## The role of ecosystem condition

Good ecosystem condition is integral to achieving good nature conservation status of habitats listed under Annex I of the [EU Habitats Directive](#) (Annex I includes those habitats considered threatened in the EU territory and whose conservation requires the designation of Special Areas of Conservation or SACs). Accordingly, assessment of condition is included alongside assessment of habitat range and threats as part of the conservation status assessment of Annex I habitats reported by EU Member States under Article 17 of the EU Habitats Directive (NPWS 2019), presenting an immediate means to identify and prioritise Annex I habitats for restoration, such as those in unfavourable-bad state. Developed to facilitate a broader view of ecosystems, including those outside of nature conservation networks, condition accounts are integral to the SEEA EA framework, relating ecosystem condition to each of the assets outlined in the extent account for a defined accounting area. Condition is specifically defined in the SEEA EA as “*the quality of an ecosystem measured in terms of its abiotic and biotic characteristics*” with a three-stage approach outlined, incorporating:

- the collation of traceable, dynamic ecosystem condition variables,
- setting reference condition and reference levels for condition variables, which allows for the development of standardised condition indicators and
- aggregation of condition indicators within and across ecosystem types.

We note that quality is assessed with respect to ecosystem structure, function and composition, which combine to underpin the ecological integrity of the ecosystem and, thereby, its capacity to supply ecosystem services (UNSD 2021).

Ecosystem accounts developed for an array of ecosystems at EU level (Tier 1), show that the condition of most ecosystems is unfavourable-bad. Wetlands (such as peatlands, coastal wetlands and floodplains) in particular, show a continued trend of deteriorating condition across the EU region. They also present a number of challenges for ecosystem accounting, which, in part, relate to inconsistencies in their classification (Maes 2020).

The SEEA EA outlines a number of potential ecosystem condition variables for wetlands, including those relating to hydrology and vegetation cover (UNSD 2021) and there is clear guidance on defined condition data required to include in SEEA EA accounts (such as condition variables to develop condition indicators) (Czúcz et al. 2021), as well as the structured approach to building condition accounts (Keith et al. 2020). However, in the absence of data relating to condition variables, EU ecosystem condition accounts, developed to date, have relied on combining information relating to pressures (such as conversion to other land-use types) with metrics, such as wetland connectivity and nutrient levels, as well as ancillary information, such as designation for nature conservation and Annex I conservation assessment (Maes 2020). The least developed aspect of the SEEA EA, with few examples where the three stages of condition accounts have been developed either at European Region or at national levels, efforts to develop more detailed condition accounts are becoming more focused (Maes et al. 2020, Keith et al. 2020, Czúcz et al. 2021), including the studies featured in this Topic Collection.

## Peatlands: wetlands poised for restoration

Peatlands are a type of wetland, characterised by complex interactions between water, peat soil, biodiversity and people. Covering less than 3% of the global land surface, they represent significant global carbon stores, substantially more than the carbon stock in the entire forest biomass globally (Joosten 2016), which cover ten times the area (30%) (Köhl et al. 2015). Apart from being long-term carbon stores (stocks), healthy peatlands provide global climate and water regulation services (Bonn et al. 2016). Widely recognised as global hotspots for biodiversity, they are also significant socio-cultural landscapes that underpin the livelihoods of communities across the globe, thereby comprising globally-important natural capital (Bonn et al. 2016). Drainage and extraction of peat degrades peatland condition, reducing the flow of ecosystem services (Evans et al. 2014, Renou-Wilson et al. 2019). From a climate regulation perspective, degradation switches peatlands from being carbon stores to carbon sources, with estimates indicating that degraded peatlands will contribute 8% of the global anthropogenic CO<sub>2</sub> emissions by 2050 (Urák et al. 2017). In addition, degradation results in reduced water quality, changes in regulation of water flow and loss of biodiversity (Martin-Ortega et al. 2014, Martin-Ortega et al. 2021). Peatland and wetland restoration, in general, are therefore viewed as a cost-effective nature-based solution, assisting in the conservation of wetland habitats, while also serving to reduce negative trends in ecosystem flows and delivering a range of co-benefits for climate, water and biodiversity (Bonn et al. 2016, Maes 2020).

## Developing condition accounts for peatlands to guide restoration targets

Building on ecosystem accounts, developed to date, for wetlands and peatlands in the [UK](#) and Netherlands (Hein et al. 2020a), in this study, we tested how to make effective use of existing datasets relating to peatland stocks (extent and condition) to assess and develop condition accounts for peatlands in two contrasting catchments in Ireland. Based on this information, we identified peatland areas at risk of not achieving reference condition and therefore, in need of restoration. Following the steps outlined in the SEEA EA (UNSD 2021), we worked at catchment scale, as it represents a distinct biophysical landscape unit with well-defined boundaries, reflecting the reporting boundary of the [EU Water Framework Directive](#). We present our findings in terms of:

1. Application of the SEEA EA framework and approach to developing ecosystem extent and condition accounts for peatlands using existing datasets.
2. Aligning information gathered under the SEEA EA accounting framework to identify peatlands at risk of not achieving reference condition and, therefore, areas requiring restoration.
3. The limitations of the approach, including data gaps and potential application to other ecosystem types.

## Methodology

### Peatlands in Ireland and study catchment accounting areas

Ireland is a global hotspot for peatlands, with over 20% of the national territory covered by peatland or peat soils (Connolly and Holden 2009). Conversion of peatlands to other land-uses (agriculture, forestry and peat extraction) is one of the main pressures on Irish peatlands requiring drainage and removal of typical peatland vegetation. Additional pressures, including overgrazing, burning and development for renewable energy infrastructure, have resulted in the loss of more than 80% of Irish peatlands (Connolly 2018). All peatland habitat types, listed under Annex I of the EU Habitats Directive, are considered to be of unfavourable-bad conservation status (Suppl. material 1) since the start of reporting (NPWS 2019). We selected two catchment areas with relatively high cover of peatland ecosystems to reflect a sub-sample of the range of peatland habitats types (ecosystem sub-types) in Ireland, including peatlands considered of nature conservation value (Annex I habitat type) and degraded peatland habitat types (Table 1).

	<b>Dargle</b>	<b>Figile</b>
Area	17,864 hectares (178 km <sup>2</sup> )	30,143 hectares (301 km <sup>2</sup> )
National context	Dublin City and north County Wicklow (east).	Offaly and Kildare (midlands).
River system (WFD code)	<a href="#">Avoca-Varty river system: (EPA WFD code: 10_5)</a>	<a href="#">Barrow river system (EPA WFD code: 14_3 and EPA WFD code: 14_14)</a>
Peatland habitat types	Upland (mountain) blanket bog and wet heathland, patchy fen remnants present.	Raised bog developed for industrial peat extraction since 1930s, patchy fen remnants present.
Peatland area designated for conservation	All peatlands (ca. 3,608 ha) conserved within the EU Natura 2000 network (nature protection areas in the EU).	A small area (ca. 264 ha) of peatlands (0.88% of total area) conserved within nationally designated sites.
Total % area of catchment designated for nature conservation	ca. 25% of total catchment area (of which ca. 20% is peatland habitats).	ca. 1.4% of total catchment area (of which < 1% is peatland habitats).

### Stakeholder engagement and data inventory

A desktop review of available national and catchment-level datasets (with particular focus on peatlands data) was undertaken. This was combined with engagement through focused workshops with peatland ecologists, NGOs and land managers, as well as through online catchment workshops. Catchment workshops involved engagement with members of state nature and environment agencies, local authorities, landowners, businesses (agriculture, forestry, peat and water companies), fisheries groups, ecologists and community groups. The workshops served to identify potential datasets as well as raise awareness as to the

SEEA EA approach and data needs (Farrell and Stout 2020). The key datasets, used for developing SEEA EA accounts for peatlands in the catchment accounting areas, were national scale, open access data (CORINE, EU Habitats Directive Article 17 and commonage assessment data, national soil data (peat texture), livestock numbers ([Central Statistics Office](#) (CSO) data) with focused catchment data used (datasets relating to industrial peat extraction) where available and relevant. These data supported building extent accounts and, alongside relevant ancillary datasets, formed the basis to develop rudimentary condition accounts. The use of the data is described where relevant and outlined in Suppl. material 2.

## Peatland ecosystem typology

A key step in the SEEA EA is identifying the range of ecosystem types and the typology used. Ecosystem types included in this study were peatlands (bogs and fens) and heathlands (wet heath), all characterised by a [peat soil](#) which has a depth of at least 45 cm on undrained land and 30 cm deep on drained land. We aligned CORINE Land Cover (CLC) Level 3 classes broadly with Level 1 (peatlands and heathlands) of the national ecosystem typology to define the main ecosystem types present in each study catchment (Table 2). These were further aligned with the [EU Eunis habitat classification](#). We note that, under the IUCN Global Ecosystem Typology (Keith 2020), bogs align with TF1.6 Boreal, temperate and montane peat bogs; fens align with TF1.7 Boreal and temperate fens and heathlands align with T3.3 Cool temperate heathlands.

Table 2.

Irish peatland and heathland national typology (national Level 3 bogs, fens, flushes and wet heathland habitat types are highlighted using italics) aligned with CORINE and Eunis classifications. Note:\* infers Annex I priority habitats.

CORINE Land Cover Classification (peatland CLC classes)				Irish National Typology (Fossitt 2000)			Eunis classification (EU HD Annex I habitats)	
Class	Sub-Class	Code	Land-cover Description	Level 1	Level 2	Level 3	Code	Name
4. Wetlands	4.1 Inland Wetlands	412	Peat bogs	Peatlands	PB Bogs	<i>PB1 Raised bogs</i>	7110; 7120	*Active raised bogs; Degraded raised bogs capable of natural regeneration
						<i>PB2 Upland blanket bog</i>	7130	Blanket bogs (*if active)
						<i>PB3 Lowland blanket bog</i>	7130	Blanket bogs (*if active)
						<i>PB4 Cutover bog</i>		

CORINE Land Cover Classification (peatland CLC classes)				Irish National Typology (Fossitt 2000)			Eunis classification (EU HD Annex I habitats)	
Class	Sub-Class	Code	Land-cover Description	Level 1	Level 2	Level 3	Code	Name
						<i>PB5 Eroding blanket bog</i>		
		411	Inland marshes		PF Fens and flushes	<i>PF1 Rich fen and flush</i>	7230; 7210	Alkaline fens; *Calcareous fens with <i>Cladium mariscus</i> and species of the Caricion davallianae
		412	Peat Bogs			<i>PF2 Poor fen and flush</i>		Not listed on Annex I, but regarded as being of special conservation importance in Ireland
						<i>PF3 Transition mire and quaking bog</i>	7140	Transition mire and quaking bogs
3. Forest and Semi-natural Areas	3.2 Shrub and/or Herbaceous Vegetation Associations	322	Moors and heathlands	Heath and dense bracken	HH Heath	HH1 Dry siliceous heath	4030	European dry heaths
						HH2 Dry calcareous heath	4030	European dry heaths
						HH3 Wet heath	4010	Northern Atlantic wet heaths with <i>Erica tetralix</i>
						HH4 Montane heath	4060	Alpine and Boreal heaths
						HD Dense Bracken		
	3.3 Open Spaces with Little or no Vegetation	334	Burnt Areas					

The national ecosystem typology provides a comprehensive synthesis of the most frequently encountered peatland ecosystem sub-types or peatland habitats in Ireland (Fossitt 2000). Level I peatlands are distinguished as bogs and fens (Level 2) and heathlands as heath and dense bracken (Level 2). Bogs are ombrotrophic ecosystems,

comprising a number of Level 3 habitats, including raised and blanket bog habitat types, with degraded habitats (cutover and eroding blanket bog) also distinguished. In Ireland, raised bogs comprise domed, deep peat masses that were preceded in development (ca. 10,000 ybp) by extensive fens, while blanket bogs occur where mild oceanic climatic conditions prevail along the western seaboard (lowland type) and on slopes of up to 15 degrees in upland areas (upland type). Fens and flushes (Level 2) are minerotrophic, occurring as localised habitats, often within larger bog complexes. Wet heathland habitats (Level 3) are also peatlands, forming a mosaic with blanket bogs on intermittent upland slopes, with peat depth < 45cm. *Active* raised and blanket bogs, and alkaline fens are priority habitats listed on Annex I of the EU Habitats Directive (Fossitt 2000). Industrial peat extraction in the Irish midlands has resulted in extensive areas of former raised bogs being extracted to lower, original fen peat layers. These degraded habitats are referred to as industrial cutaway peatlands (Bord na Mona 2016).

### Building SEEA EA accounts

Using relevant datasets available, we applied the process steps as outlined in the SEEA EA (UNSD 2021) to develop extent and condition accounts.

**Extent:** We note that the SEEA EA requires a seamless spatial dataset to develop extent accounts. While a number of commissioned peatland surveys (using the national and/or Eunis typology), gathered at various time periods, were available for parts of the study areas, their fragmented and partial coverage rendered them unfit for use, but relevant in verifying the peatland habitat type. Therefore, in the absence of a continuous, national peatland ecosystem map or a land-cover map detailing peatland habitats, CORINE land cover (25 ha MMU or Minimum Mapping Unit) provided the best available time series datasets at national scale to form the basis of catchment scale extent accounts to show short term changes over time (data available for 2000, 2006, 2012 and 2018). Data were analysed using GIS tools (ArcGIS) to develop extent accounts (maps and tables). We note that, given the relatively coarse resolution of the CORINE landcover status layers, while they serve to show general trends, they are not reliable for developing change accounts (EEA 2019) and change in extent accounts were developed using the CORINE Change product (5 ha MMU). Supplementary datasets provided more detail on the extent of specific peatland types (Article 17 datasets and industrial peat extraction data). We used peat soil texture datasets, developed at national level, as an indicator of the former extent of peatland in each catchment (pre-2000) as demonstrated in Farrell et al. (2021b).

**Condition:** Peatland condition was assessed using datasets gathered to support reporting under the EU Habitats Directive (data collated for Article 17 national reporting of Annex I habitats), survey data commissioned to report peatland degradation under livestock grazing commonage assessments (2000 and 2012) and data collated by the Irish peat extraction company (Bord na Móna). Ground-truthing (site inspection and vantage point survey by a trained peatland ecologist), use of aerial imagery ([Google Earth Pro](#)) and stakeholder engagement (local knowledge) were incorporated to assess peatland condition in each catchment.



## Identifying peatland areas for restoration

Following [guidelines](#) for the assessment and reporting of the conservation status of habitats reported under Article 17 of the EU Habitats Directive, we aligned the condition assessment (developed for the condition accounts) alongside extent account data (range, area) and future prospects (based on knowledge of pressures and threats) and developed an overall assessment of peatland status and trends for both catchments. Once one parameter (structure and function, range and area and future prospects) was identified as having bad prospects, the assessment of future prospects was ‘unfavourable-bad’ (Bad). We used the national typology/Annex I habitats descriptions as reference condition for blanket bog, raised bog, wet heath and fen (Fossitt 2000) and, where a peatland was classified as a degraded peatland type, such as cutover bog, the reference condition was considered as rewetted, revegetated and environmentally stabilised. Where the peatland was considered at risk of not achieving the reference condition without active restoration, it was classed as being *At Risk*.

Table 3.

Ecosystem extent accounts showing area (ha) and percentage cover (in italics) of CLC Level 3 peatland classes in the Dargle and Figile catchment areas for 2000, 2006, 2012 and 2018. Note: minor discrepancies in summing of percentage cover relate to rounding off figures.

CLC Code	CLC (Level 3) peatland classes	Dargle								Figile							
		2000		2006		2012		2018		2000		2006		2012		2018	
322	Moors and Heathlands	0	<i>0</i>	2,214	<i>13</i>	3,125	<i>18</i>	3,157	<i>18</i>	0	<i>0</i>	0	<i>0</i>	0	<i>0</i>	0	<i>0</i>
334	Burnt areas	0	<i>0</i>	0	<i>0</i>	0	<i>0</i>	65	<i>&lt;1</i>	0	<i>0</i>	0	<i>0</i>	0	<i>0</i>	0	<i>0</i>
412	Peat Bogs	4,062	<i>23</i>	1,897	<i>11</i>	1,201	<i>7</i>	1,201	<i>7</i>	10,979	<i>36</i>	10,024	<i>33</i>	9,659	<i>32</i>	9,512	<i>32</i>
	<b>Total</b>	<b>4,062</b>	<b><i>23</i></b>	<b>4,111</b>	<b><i>23</i></b>	<b>4,326</b>	<b><i>24</i></b>	<b>4,423</b>	<b><i>25</i></b>	<b>10,979</b>	<b><i>36</i></b>	<b>10,024</b>	<b><i>33</i></b>	<b>9,659</b>	<b><i>32</i></b>	<b>9,512</b>	<b><i>32</i></b>

## Results

### Peatland extent accounts

Our extent accounts are outlined in Table 3, with supporting information in relation to ecosystem extent summarised in Table 4 and additional information in Suppl. material 3. CORINE datasets provided a coarse indicator of peatland ecosystem extent for available time-series data, with 2018 extent account data illustrated in Figs 1a, 2a. While the CORINE land-cover data show a slight increase in the Dargle peatland ecosystem extent between 2000 and 2018, the CORINE change account data verified an overall slight decline in peatland classes in the Dargle (< 0.5% decrease), with a similar decline in the Figile (< 1% decrease) (Table 4, Suppl. material 3), highlighting the need to use the more detailed CORINE Change product to verify changes. Peat soil texture data (Figs 1b, 2b)

showed that, for both catchments, peatlands were originally more extensive (up to twice the present cover) and highlighted a significant decline in peatland cover prior to 2000. These former peatlands have been converted to other land-cover types including agricultural grassland and commercial forestry (Suppl. material 3). In terms of peatland habitat types (ecosystem sub-types) present, Article 17 data, overlain on peat soil texture data, were considered the best representative dataset showing the present peatland ecosystem extent in the Dargle (Fig. 1b). In the Figile, Article 17 data were considered the best representative dataset for the extent of active raised bog habitat, while CORINE data outline the overall extent of peatlands in the catchment (all habitat types combined) (Fig. 2a). We note patches of Annex I fen habitats were reported present in both catchments (point data in Figs 1a, 2a, Suppl. material 3).

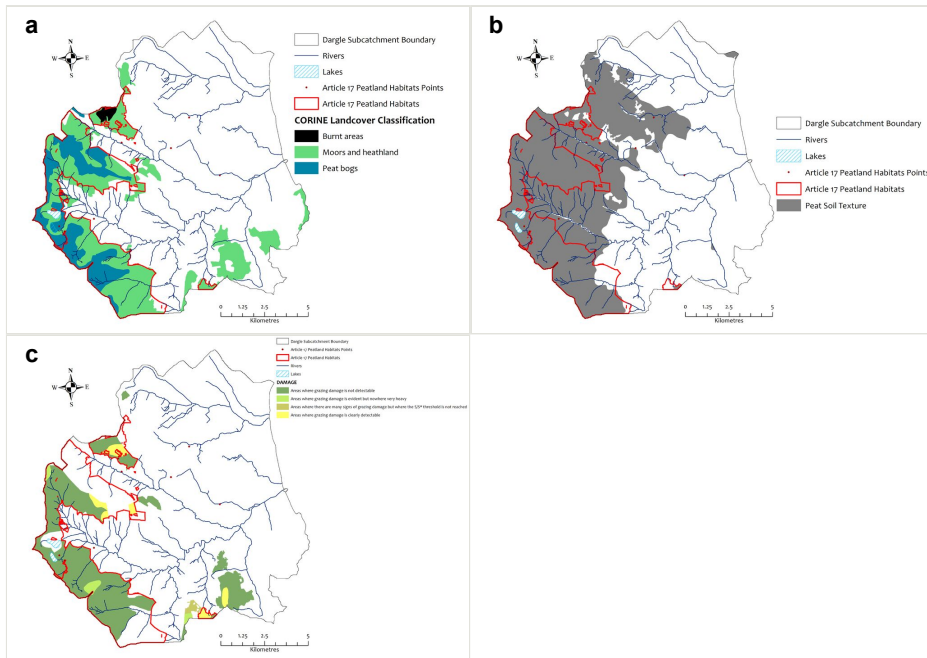


Figure 1.

Dargle data panel: (a) The extent of A17 peatlands (red outline) overlain on CORINE 2018 peatland classes; (b) The former extent of peatlands (pre-2000) is shown by the extent of soil of peat texture with present day extent of A17 peatlands shown in red and (c) condition assessment of peatland commonages (2001 data).

## Peatland condition accounts

Data available on peatland condition for the Dargle included commonage survey data from 2001 and a desktop survey of the Wicklow Mountains Special Area of Conservation (SAC, part of the EU Natura 2000 conservation network) which partially overlaps with the Dargle catchment and is based on 2006 data. Commonages comprise a mosaic of habitats including peatlands, dry heathland and upland habitats including sparsely vegetated areas,

grasslands and scrub, which are used by a number of landowners with shares in the commonage to graze livestock. Data relating to the condition of commonage areas in Ireland were gathered nationally in the early 2000s in response to overgrazing pressures in upland areas. Condition data available for the Figile comprised a desktop survey of raised bog remnants and industrial peat extraction data. No site assessment surveys under Article 17 reporting were available for peatland habitats in either catchment. We present our rudimentary condition account in Table 5, describing the summary findings in the text with supporting detail in Suppl. material 3.

Table 4.

Summary supporting information relating to the extent of peatlands in the Dargle and Figile catchments (% catchment) and area of Annex I peatland habitats (hectares and total %).

<b>Dataset</b>	<b>Dargle</b>	<b>Figile</b>
CORINE 2000 peatland classes	23%	36%
CORINE 2018 peatland classes	25%	32%
CORINE change product 2000-2018	< -0.5%	< -1%
Annex I peatland habitats	20%	< 1%
Peat soil texture (former peatland extent pre-2000)	41%	69%
<b>Annex I peatland habitats</b>		<b>Area ha</b>
<b>Code</b>	<b>Habitat name</b>	
4010	Wet Heath	3,258
7110	Raised Bog (Active)	0
7130	Blanket Bog (Active)	2,790
7140	Transition Mires	3
<b>Total Annex I habitats considering overlaps (in the Dargle, wet heath and transition mires overlap with blanket bog in the Article 17 datasets).</b>		<b>3,608 (ca. 20%)</b>
		<b>264 (&lt; 1%)</b>

## Dargle peatland condition assessment

*Commonage data:* Relatively small areas of peatlands showed heavy signs of grazing damage in 2001 (Fig. 1c). We note that not all peatlands are included in the commonage and not all commonage areas are peatlands. No repeat survey data are available, but farm census data show that sheep numbers in the catchment have been reduced (Suppl. material 3).

*Desktop survey:* These data showed that, for the area surveyed, peatland habitats comprised ca. 50% degraded peatland habitats (cutover and eroding bog) and ca. 50% Annex I peatland types, occurring in a mosaic with dry heathland alongside patches of wet grassland, scrub and plantation (described in detail in Suppl. material 3). There were no data relating to condition or trends for the Annex I habitats.

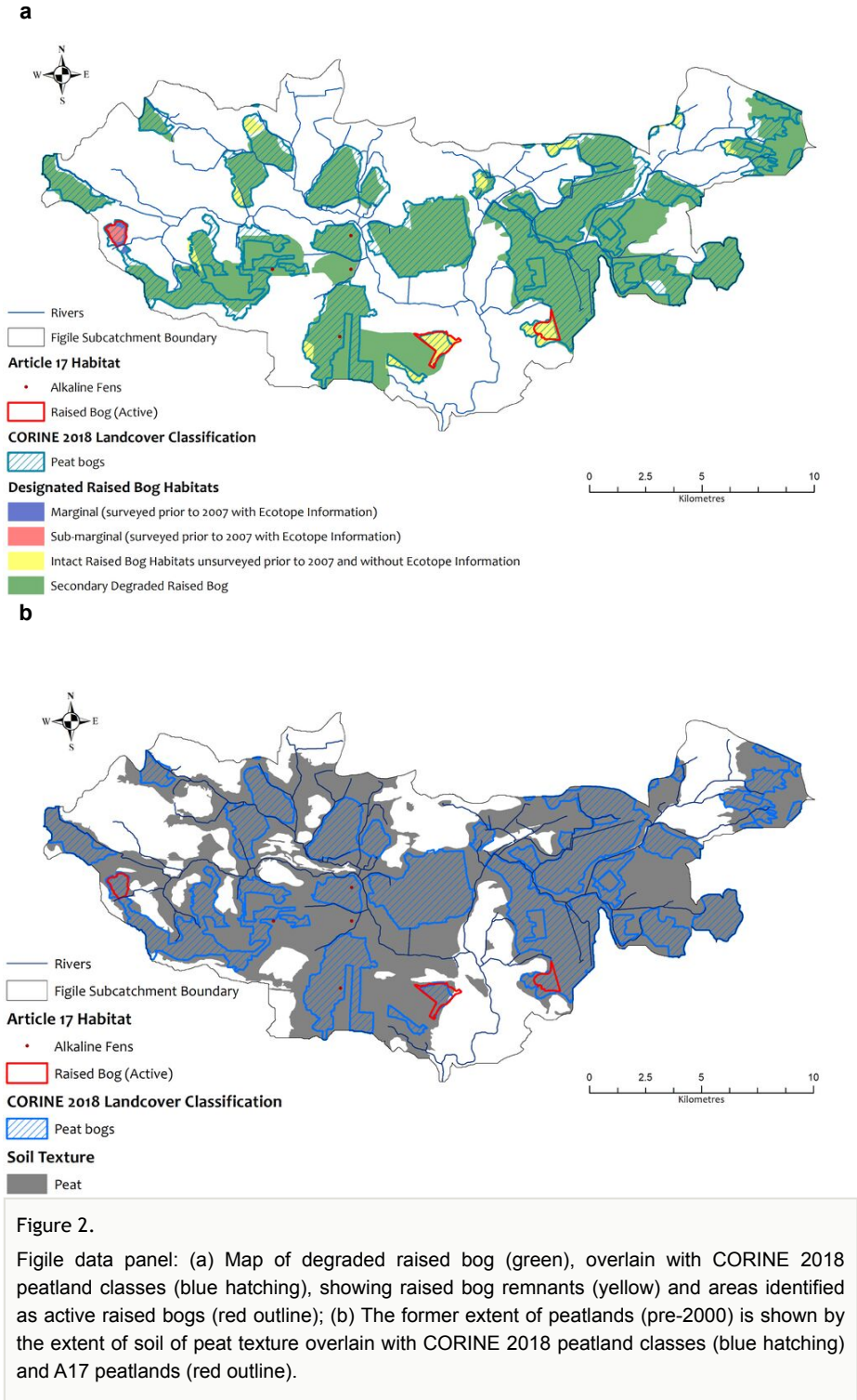


Table 5. Rudimentary condition accounts for the Dargle and Figile accounting areas.		
Condition account information	Dargle	Figile
<b>Available datasets</b>		
Commonage data (2001) and livestock numbers (2010)	Areas of heavy damage reported in 2001 (ca. 1% peatland area heavily damaged); sheep numbers reduced (2010 data).	No commonage areas present.
Peatland habitat surveys: Wicklow Mountains SAC (2006), raised bog remnant survey (2013) and industrial peat extraction data (2019)	50% peatland habitats classified as degraded types (eroding and cutover bog habitats).	Fragments of active raised bog remaining in 2013; 35% bare peat and > 90% classified as degraded peatland habitat types (2019 data).
<b>Assessment of condition variables based on Google Earth imagery (2009 and 2020 data)</b>		
Exposed, bare peat	Area of bare peat increased between 2009 and 2020.	Extensive bare peat (> 30%) in 2020; the area of bare peat decreased between 2009 and 2020.
Active peat erosion	Area of exposed subsoil (gravels) increased between 2009 and 2020.	Not evident.
Burn scars	Evident in localised areas.	Not evident.
Drainage	Drains associated with former turf cuttings still evident.	Intensive drainage system evident across all peatlands.
<b>Overall condition (2021)</b>	<b>Bad</b>	<b>Bad</b>

*Aerial imagery, site visits and stakeholder knowledge:* Comparing 2009 and 2020 aerial imagery datasets highlighted localised areas of gullying and active erosion at the upper reaches of the catchment, increasing the exposure of areas of underlying gravels. Comparison of the area of exposed gravel between 2009 and 2020 indicates erosion is ongoing. Burn scars were clearly visible with uncontrolled burning occurring regularly, according to local stakeholder knowledge. Former peat cuttings were clearly visible along with an extensive drainage network. While there was no active peat cutting visible or reported by locals, drainage networks remain active. Recreational paths showed signs of trampling and bare peat exposure.

*Dargle overall condition assessment:* The levels of degradation varied within the catchment and between peatland habitat types (Annex I blanket bog and wet heathland and cutover and eroding bog), but overall, the condition was impacted negatively with ongoing erosion

and degradation of the peatland habitats and the condition of the Dargle peatlands was considered Bad.

### **Figile peatland condition assessment**

*Raised bog remnant desktop survey:* These data outline the extent of remaining raised bog remnants at the margins of larger industrial cutaway peatland units (Fig. 2a). Overlaying this dataset with Article 17 reporting data showed that three areas of remnant raised bog were identified as active raised bog areas (total area 264 ha), while the remainder was classified as secondary, degraded raised bog.

*Industrial peat extraction data:* These data show that the secondary, degraded raised bog comprised industrial peatland areas (active extraction and cutaway) (Suppl. material 3). The extraction areas comprised a range of habitats including bare peat (corresponding to active peat extraction areas in 2019), patches of cutover bog at margins of industrial units, with an array of emergent pioneer habitats established on areas taken out of peat extraction (pioneer cutaway habitats, scrub, wetlands and woodlands).

*Aerial imagery, site visits and stakeholder knowledge:* Aerial imagery datasets verified the information provided by available datasets and confirmed there were few remaining examples of near intact raised bog habitats in the study catchment. These remnants were affected by drainage and fragmentation effects. Most of the peatland areas comprised industrial peatlands that have been extracted to lower fen peat layers. Bare peat areas were clearly evident along with signs of pioneer habitats emerging on areas no longer used for active peat extraction. These included rudimentary fen (where drainage channels are inactive), scrub and woodland. At the margins of the industrial extraction areas, there were extensive areas of domestic turf cutting which comprised bare peat spread-ground adjoining turf banks/cutting faces at the edge of raised bog remnants. To support industrial and domestic peat extraction, an extensive, active drainage network is in situ which also facilitates ongoing drainage of adjoining agricultural and afforested lands.

*Overall condition assessment:* The levels of degradation varied within the catchment and between peatland habitat types. For all three distinguishable types (Annex I raised bog, industrial cutaway peatland and cutover bog), the condition was impacted negatively with ongoing drainage and degradation of the peatland habitats and the condition of the Figile peatlands was considered Bad.

### **Peatland areas at risk of not achieving reference condition levels**

Linking the overall condition assessment with the overall decline in peatland area in both catchments (41% to 20% in the Dargle, 69% to 37% in the Figile prior to 2000) and knowledge of pressures (historical turf cutting and overgrazing, combined with ongoing recreational use in the Dargle contributing to ongoing erosion and exposure of bare peat; ongoing industrial peat extraction activities and domestic turf cutting in the Figile), we developed an assessment of the risk of peatlands in both catchments of not reaching reference condition in the absence of restoration measures (Table 6). We note that the

reference condition selected is the natural state of the peatlands as described in the national typology (Fossitt 2000), as recommended by the SEEA EA (UNSD 2021) and where peatlands have been degraded to the extent they cannot return to their original, former reference condition, the new reference condition was considered as rewetted, revegetated and environmentally stabilised.

Table 6.					
Likelihood (risk) of peatland habitat types not achieving reference condition in the absence of restoration measures in each study catchment.					
Peatland type	Reference type	Extent (stable, declining or increasing)	Condition (2021)	Pressure and threats	Risk level
<b>Dargle peatlands</b>					
Wet Heath and <i>active</i> Blanket Bogs	Annex I (4010 and 7130)	<b>Declining:</b> signs of erosion; long term decline based on former peat soil extent; slight recent change shown in CORINE change product.	<b>Bad:</b> more than 50% peatland areas showing signs of degradation.	Historical drainage for turf cutting still active; effects of past overgrazing evident; ongoing soil erosion and uncontrolled burning; ongoing trampling and exposure of bare peat due to recreational use; ongoing conversion to other land-use types.	At risk
					At risk
Transition Mires	Annex I (7140)	<b>No data:</b> present extent 3 ha (no historical data).	<b>Bad:</b> generally found within blanket bog complexes; risk characterisation can be inferred from overall blanket bog assessment.		At risk
Degraded Wet Heath and degraded Blanket Bogs	Annex I (4010 and 7130); new reference levels to be identified in heavily degraded areas.	<b>Declining:</b> Increasing signs of ongoing erosion; long term decline based on former peat soil extent; slight recent change shown in CORINE change product.	<b>Bad:</b> more than 50% peatland areas showing signs of degradation.		At risk
<b>Figile peatlands</b>					
Active and degraded Raised bog	Annex I (7110 and 7120)	<b>Declining:</b> 264 ha of former extensive raised bog (> 10,000 ha) remain with limited patches of remnant active raised bog.	<b>Bad:</b> fragmented nature, size and ongoing drainage limits prospects to return to active raised bog.	Turf cutting still active at margins of raised bog habitats; effects of past cutting evident; restoration is required to conserve and restore/maintain Annex I habitats.	At risk

Peatland type	Reference type	Extent (stable, declining or increasing)	Condition (2021)	Pressure and threats	Risk level
Cutaway industrial peatland	Rehabilitated industrial cutaway: fen, wetland/ woodland mosaic.	<b>Stable:</b> peat extraction ceased in 2020; future decline may be due to conversion to other ecosystem types.	<b>Bad:</b> presently drained for industrial extraction with extensive bare peat areas.	Pressures are reducing, active measures are in planning phase to rehabilitate the industrial cutaway peatlands.	<i>At risk</i>
<b>Dargle and Figile peatlands</b>					
Cutover bog	Rewetted cutover bog.	<b>Figile (declining):</b> domestic turf extraction is ongoing and may increase. <b>Dargle (stable):</b> turf cutting inactive, but drains remain active.	<b>Bad:</b> Intensively drained with extensive bare peat in Figile, turf banks partially revegetated in Dargle, but drains active.	<b>Figile:</b> turf cutting likely to continue and may increase/extend to other areas. <b>Dargle and Figile:</b> at present, there is no licensing obligation to rehabilitate.	<i>At risk</i>
Fens	Annex I (7230, 7210)	No data	No data	No data	No data

**Annex I habitats:** In the absence of restoration measures, all Annex I peatland types are *At Risk* of not reaching Favourable conservation status, relative to the reference condition (Annex I habitat type). Note that Favourable conservation status, as defined under the EU Habitats Directive, infers that habitats must have sufficient area and quality to ensure maintenance into the medium to long term, along with favourable future prospects in the face of pressures and threats (NPWS 2019).

**Degraded Annex I habitats:** In the Dargle, areas classified as Annex I habitats include localised patches of eroding bog, cutover bog and areas that show signs of overgrazing and trampling (bare peat) and/or burn scars. Given ongoing erosion and the scale of degradation, these degraded areas are at a higher risk of not achieving Favourable conservation status. Restoration of Annex I habitat is not feasible in parts of these areas (such as where peat has eroded to sub-peat gravels), requiring a new reference condition to be established. In the Figile, Annex I degraded raised bog is supporting active raised bog. However, the fragmented nature and size of isolated active raised bog remnants, combined with the ongoing drainage at margins, reduces the potential to restore these areas to Annex I priority active raised bog habitat. Therefore, these habitats are considered *At Risk* of not reaching Favourable conservation status, relative to former reference condition (Annex I habitat type).

**Industrial cutaway peatlands:** these areas have been extracted to lower fen peat layers. Research to date shows that natural regeneration and rehabilitation of industrial cutaway raised bogs results in establishment of fen peatlands (through rewetting) with wet woodland emerging in dry areas that remain above the water-table (Rowlands and Feehan 2000). Integrated Pollution Control Licensing (overseen by the Environmental Protection Agency) requires these areas to be rehabilitated to an environmentally stabilised condition (Bord na Mona 2016). The reference condition is, therefore, considered fen, wetland and



woodland mosaics. While peat extraction on bare peat areas ceased in 2020, the drainage system remains in situ and, until restorative measures are implemented, the industrial cutaway peatlands are considered *At Risk* of not achieving the reference condition (fen, wetland and woodland mosaics).

**Cutover bog:** these areas are diverse in terms of scale and level of intensity of use (most areas are inactive in the Dargle, but actively being cut in the Figile). Domestic turf cutting is not licensed and there are no legal obligations to rehabilitate areas when peat extraction ceases. However, inactive cutover areas have been shown to recover typical peat-forming vegetation with rewetting and other restorative measures (Crowley et al. 2021). Given the continued effects of active cutting in the Figile, the effects of ongoing drainage and given that no active restoration has taken place in either catchment with no legal obligations to do so, cutover bog areas are considered *At Risk* of not achieving the reference condition (rewetted cutover bog).

## Discussion

### Understanding extent accounts

While data relating to peatland condition were limited for our study catchments, we demonstrated that incorporating information relating to peatland ecosystem sub-types or habitat types, gathered under extent accounts, helped to build rudimentary peatland ecosystem condition accounts at catchment scale. We note that ecosystem accounts, developed at Tier I level in the EU region, generally refer to high level peatland and heathland ecosystem types, such as those outlined in CORINE land-cover classes Peat Bogs and Moors and Heathlands (EEA 2019). Working at lower levels, such as that of catchment scale, a more detailed ecosystem classification supports accounting in relation to understanding and tracking conversions between peatland habitat types, particularly in relation to trends in and levels of degradation, thereby providing basic information to identify realistic restoration targets as required under the EU nature restoration plan (Vysna 2021).

In the case of peatlands, we note that intact peatland habitat types, as defined under the Irish national typology, are, in the main, considered Annex I habitats (blanket bog, raised bog, wet heathland, alkaline fen) and these are all included under Article 17 reporting. This infers that remaining peatlands are *other* peatland habitat types derived from former Annex I types, classified as eroding bog, industrial cutaway peatland or cutover bog. By inference, these peatlands are considered to be in a degraded (or bad) condition. At catchment and local scales, peatland habitat type is, therefore, considered a means to provide information in relation to condition. It is noted that a change in condition also affects extent accounts, for example, where intensified drainage and/or extraction of peat converts an Annex I bog to a cutover bog (from good to bad condition) or where restoration restores a drained, degraded raised bog to an *active* raised or blanket bog (from bad to good/better condition). These changes would typically be recorded in the SEEA EA extent and change in extent, accounts as a conversion from one ecosystem type to another (UNSD 2021).

Understanding how and why peatland types cross threshold levels and are converted to other peatland habitats and how that is related to pressures and use (for example, blanket bog converted to eroding bog, as a result of overgrazing), is integral to developing peatland ecosystem stock accounts and, equally, ecosystem services accounts, as there are consequences for ecosystem service provision (Kimmel and Mander 2010). For example, degraded heathlands are often characterised by burned areas and/or bare peat, which become dominated by bracken (*Pteridium aquilinum*), with resulting loss of services and flows relating to biodiversity and grazing (Marrs et al. 2008). Equally, dry heathlands may be derived from drainage of blanket and raised bogs, with resultant effects on services, such as regulation of water flows. In this latter example, peatlands were converted from wetlands to dry heathlands, but have the potential to be restored to original peatland condition (Bellamy et al. 2011). A more challenging conversion is that of restoring forest or grasslands, established on peatlands, to the former original peatland. In both of our study catchments, up to 50% of the original peatland area was converted to grassland or forest ecosystem types prior to 2000. Both of these 'derived from peatland ecosystems' comprise land-cover and land-use types on peat soils that have been shown to increase emissions of greenhouse gases. For example, conversion of peatlands to commercial conifer plantations has been shown to have long-term climate warming effects (Jovani-Sancho et al. 2021). Peatland restoration measures (such as tree removal and rewetting) may reverse these trends (Artz et al. 2013, Andersen et al. 2016). Extending the accounting framework to include these 'derived from peatland ecosystems' would identify those areas where restoration measures would deliver benefits for climate, water and biodiversity, while, at the same time, tracking changes in stocks relating to agricultural and forest ecosystems and related flows of carbon as shown by work in The Netherlands (Hein et al. 2020a), serving to provide information for the National Inventory Reporting for LULUCF.

One of the challenges identified for developing ecosystem accounts for wetlands is their misrepresentation in different classification systems (Maes 2020) and, as we have shown, the boundaries are not always clear. A well-defined classification of peatland and wetland ecosystem types (and, inter alia, all ecosystem types) is essential to establish the relevant content of the ecosystem extent account, which underpins all other accounts in the SEEA EA framework (UNSD 2021). Furthermore, working at catchment and lower scales requires more detail on ecosystem sub-types or habitat level descriptions. A detailed peatland map to show extent of peatland habitat types aligned with the national typology at a resolution appropriate to monitoring changes at a defined site/accounting area level, would enable more refined ecosystem accounting at catchment and lower scales and facilitate more accurate tracking of changes over time. For example, extent data, relating to the area of domestic turf extraction (cutover bog), would underpin an assessment of this peatland type which is considered to be extensive in Ireland, but currently not mapped (Connolly 2018). We note that there are limited data relating to fens and these require a targeted survey to ensure they are included in peatland accounting frameworks. Furthermore, the expansion of fen (and wet woodland) habitats on industrial cutaway and cutover bogs in the future will present a significant change in ecosystem accounts for catchments characterised by industrial peat extraction (Rowlands and Feehan 2000, Farrell and Doyle 2003, Renou et al. 2006).

## Understanding condition accounts

In relation to the three-stage approach to develop condition accounts (UNSD 2021), we present condition accounts, based on what was available and feasible at this time. Datasets relating to ecosystem condition variables were limited and we relied on extent data, ancillary information gathered at varying intervals and expert ecological opinion to develop rudimentary condition accounts. Drainage and disturbance (including erosion) provided useful information in relation to peatland use and pressures (Connolly and Holden 2011), while land conversion data provided further relevant information relating to pressures, reflecting work carried out at EU scale (Maes 2020). However, condition accounts should be based on measured condition variables (Czúcz et al. 2021) and in order to address data gaps, further work should focus on identifying relevant variables in order to build accounts aligned with the SEEA EA framework (Keith et al. 2020). More widespread data gathering (at standardised time intervals) relating to specific and relevant peatland condition variables (as defined by Czúcz et al. 2021), such as extent of bare peat, peat depth (required to assess carbon stocks), water level (drainage intensity) and presence of characteristic species and/or plant communities would facilitate building stage one condition accounts as outlined in the SEEA EA (Keith et al. 2020, UNSD 2021), as well as providing information in relation to supply of ecosystem services, such as carbon storage and sequestration and regulation of water flows (Farrell et al. 2021b).

The selection of realistic reference conditions for ecosystem types and corresponding reference levels for condition variables is fundamental to developing stage two of SEEA EA condition accounts (Keith 2020) and also critical in terms of identifying restoration targets for ecosystems in general and as shown in this study for specific peatland habitats or ecosystem sub-types. While the SEEA EA provides guidance (UNSD 2021), the selection of reference condition levels for condition variables should reflect local and regional contexts to address geographical variation of peatland ecosystems (and wetland ecosystems, in general) at national scales, as well as across the EU (Keith et al. 2020). For Annex I habitats, reference conditions can be established with relative ease, while those habitats beyond legal reporting frameworks will require more detailed analysis. While detailed conservation status assessments are carried out for a relatively small area of the national peatland inventory and only for Annex I habitats (NPWS 2019), the approach used here could be extended with relative ease to develop assessments for a wider range of peatland-dominated catchments and/or landscape units. Combining these with EU Water Framework Directive data, collected at sub-basin level, would serve to link peatland status and trends, with trends in the ecological status of waterbodies (Farrell et al. 2021b). As well as making use of ready-made EU reporting frameworks, collating information across a range of inter-related policies is one of the aims of the SEEA EA in terms of integrating natural systems into policy- and decision-making (Farrell et al. 2021a).

Development of standardised ecosystem condition indicators, such as those relating to peatland biodiversity (for example, the presence or absence of bird species as demonstrated in the [UK peatland ecosystem accounts](#)), and incorporating citizen science and remote sensing approaches would facilitate collection of repeatable, time-series data and development of stage two and stage three SEEA EA condition accounts. Having

standardised indicators would also allow the development of a scale of degradation relating to the condition of peatland habitat types, assisting in prioritising areas for restoration, while also serving to track recovery by means of condition accounts developed over time (Keith et al. 2020, Maes et al. 2020).

## Concluding comments

Combining available datasets with ecological expert opinion under the SEEA EA framework, we assessed the status and trends in peatland stocks at catchment scale. Our condition assessments reflect the overall unfavourable-bad national conservation assessment of peatland habitats (NPWS 2019), as well as general trends across the EU in relation to wetlands (Maes 2020). All peatland areas in our study catchments were considered *At Risk* of not achieving reference conditions unless restoration measures were undertaken. In some instances, restoration is considered feasible, while in other cases, the peatland habitats have crossed a threshold and cannot be restored to their previous reference condition, requiring a new reference condition to be set, as shown in the case of industrial cutaway peatlands (Rowlands and Feehan 2000, Farrell and Doyle 2003). Despite limited data, the approach, outlined here using the SEEA EA framework, could serve as the basis for development of a national risk register of peatland stocks and support the prioritisation and targeting of available resources for optimal returns on peatland restoration. Aligning the SEEA EA framework with restoration frameworks and tools, such as the *International Principles and Standards for the Practice of Ecological Restoration* and the *Restorative Continuum*, developed by the Society of Ecological Restoration (Gann et al. 2019), would combine established tools and frameworks to support monitoring of changes in condition (related to reducing pressures, as well as active restorative measures) over time.

Further work to develop accounts for ecosystem services would assist in developing a broader risk register (relating to potential reductions in or loss of flows, including services and benefits), as well as opportunities to realise potential co-benefits of restoration relating to climate, water, biodiversity and sustainable development (Bonn et al. 2016), across the full peatland inventory. While we highlighted a number of options to gather data to build more robust, time-series extent and condition accounts, we note that, in the absence of comprehensive data, bringing information under the SEEA EA framework is a good starting point with the integration of expert ecological opinion considered essential to ensure development of reliable accounts.

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## Hosting institution

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## Conflicts of interest

The authors have declared that no competing interests exist.

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## Supplementary materials

### Suppl. material 1: Conservation Status [doi](#)

**Authors:** Farrell et al.

**Data type:** Excel sheet

**Brief description:** Conservation Status of Annex I peatland habitats in Ireland (2007, 2013 and 2019).

[Download file](#) (9.56 kb)

### Suppl. material 2: Datasets [doi](#)

**Authors:** Farrell et al.

**Data type:** Excel sheet

**Brief description:** Datasets reviewed and utilised to develop peatland extent and condition ecosystem accounts.

[Download file](#) (12.97 kb)

### Suppl. material 3: Supporting data [doi](#)

**Authors:** Farrell et al.

**Data type:** Varied datasets applied to provide information for condition assessments.

**Brief description:** Data supporting ecosystem extent and condition accounts.

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