Optimising Water Quality Returns from Peatland Management while Delivering Co-Benefits for Climate and Biodiversity

Synthesis Report

Report produced for An Fóram Uisce

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Introduction

This synthesis report is based on the scoping study produced for An Fóram Uisce. This study was split into five key work packages.

Work package 1 is a review of national and international literature relating to the effects of drainage and **rewetting of peatlands**, with a focus on water quality impacts, as well as greenhouse gas (GHG) emissions and biodiversity.

Work package 2 reviews **carbon cycling** in drained and rewetted peatlands with a comparison with observations from natural peatlands, including gaseous and fluvial carbon dynamics, using data from studies based in Ireland and the United Kingdom.

The third work package focuses on **social values** and provides a detailed overview of cultural ecosystem services relating to peatlands, with a review of the services and disservices provided in Ireland.

Work package 4 reviews **current and alternative management options** for different peatland uses (extraction, forestry and agriculture) in terms of reducing negative impacts on the environment.

The final work package provides **strategic guidance**, which is split into four key priority areas, and identifies where resources are needed for implementation.

This scoping report will inform future peatland management in Ireland and recommendations should be used to enhance future decisions involving peatland management, in order to optimise water quality, while delivering co-benefits for biodiversity and climate change mitigation.

1. Rewetting degraded peatlands

1.1 Overview of peatland drainage and rewetting in Ireland

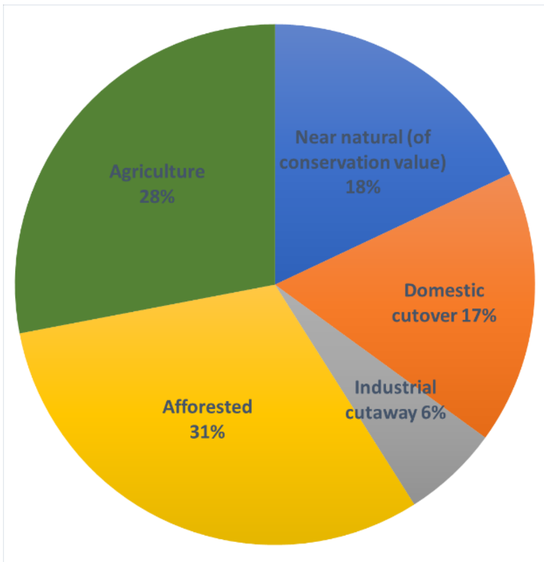


Figure 1: Estimates of area of peatland in Ireland under major land use classifications.

Irish peatlands have developed over millennia to cover just over a fifth (c. 1.46 million ha) of the national land area. Ireland has had a long history of draining its peatlands (bogs and fens), which peaked in 1920s for domestic peat extraction, but has continued in the last century for a number of land uses, including industrial peat extraction, commercial forestry and agriculture. Presently, just 18% of peatlands are classed as 'near-natural' and considered to be of conservation value, whilst 82% are classified under other land uses that involved some form of drainage (Figure 1). Many bogs and fens previously drained for extraction or agriculture have been abandoned and continue to negatively affect nearby water quality as well as being a source of GHG emissions.

Rewetting peatlands has been identified as an important management technique to improve water quality, reduce GHG emissions, improve carbon sequestration, and promote biodiversity (Parish et al., 2008, Bonn et al., 2014). There has been increasing pressure to rewet sites in Ireland following the publication of the Bogland report in 2011, which recommended that cutaway peatlands be rewetted and revegetated where possible (Renou-Wilson et al., 2011). Whilst there has been a move towards more sustainable management of peatlands, restoration has been limited mainly to the least degraded sites already under conservation designations where restoration is easier to achieve. Rewetting and revegetation of more degraded sites (the vast majority of bogs) is key to sustainable peatland management in Ireland, and yet this activity has been negligible hitherto. The area of peatland used for pasture and forestry that has been rewetted is unknown and is likely to be very low. For industrial extraction, Bord na Móna have restored 1200 ha of raised bogs to date, with plans to restore a further 1000 ha as part of their Raised Bog Restoration programme (EPA, 2017), although these were sites where mining had not taken place, and where restoration was easier to achieve.

Photo of drains in active (left) and recovering (right) extraction bogs. Photo: David Wilson.

Recent changes in the extraction industry, including cessation of extraction for electricity production and horticulture (Bord na Móna), mean large areas of severely degraded peatland are now closed for extraction and open to other land uses. The recently announced Enhanced Peatland Rehabilitation Scheme means that 'enhanced rehabilitation' or restoration will take place on 33,000 ha (Bord na Móna, 2020). It should be noted that while Bord na Móna recently announced the cessation of extraction for horticultural products, private companies may well continue to extract.

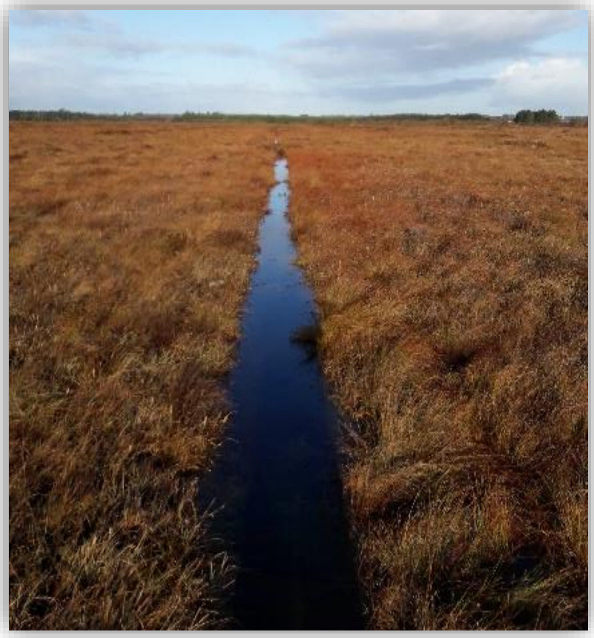
1.2 Impacts of drainage and rewetting

Draining peatlands degrades the quality of nearby surface waters, and while improvements can be achieved through rewetting, this is dependent on site-specific factors, such as the degree of damage, peat characteristics and so on. Studies (both national and international) show concentrations of nitrogen (ammonium, nitrate), phosphorus, base cations, heavy metals, dissolved organic carbon (DOC) and particulate organic carbon (POC) increase with drainage, although this depends on site specific characteristics and management. In addition, drainage impacts on peatland hydrology by lowering the water table and altering the flow regime, including increases in infiltration rates and baseflows, and the formation of pipes and macropores, lead to greater transport and mobility of pollutants. A summary of changes in water quality indicators that have been observed following drainage and peatland utilisation in Ireland are summarised below in Table 1. The majority of water quality research in Ireland relates to commercial forestry, and there has been limited studies on the effects of peat extraction and agriculture on organic soils.

Table 1: A summary of studies that have found changes in water quality indicators (nutrients, fluvial carbon and acidity) with peatland drainage and utilisation in Ireland.

Water quality indicator		Study	Management
Nitrogen	Total nitrogen	HYDROFOR Project (Kelly-Quinn et al., 2016)	Drainage, fertilisation and afforestation
	Ammonium	Cummins and Farrell (2003a)	Drainage, clearfelling, fertilisation, reforesting
	Nitrate	Cummins and Farrell (2003a)	Drainage, clearfelling, fertilisation, reforesting
Phosphorus		Cummins and Farrell (2003b)	Drainage, clearfelling, fertilisation, reforesting
		Jennings et al. (2009)	Drainage, afforestation
		HYDROFOR Project (Kelly-Quinn et al., 2016)	Drainage, fertilisation and afforestation
		Renou-Wilson and Farrell (2007)	Drainage, fertilisation, and afforestation on cutaway
		O'Driscoll et al. (2011)	Drainage, clearfelling
		Rodgers et al. (2010)	Drainage, clearfelling
Heavy metals	Potassium	Cummins and Farrell (2003a)	Drainage, clearfelling, fertilisation, reforesting
	Manganese	HYDROFOR Project (Kelly-Quinn et al., 2016)	Drainage, fertilisation and afforestation
	Magnesium	Cummins and Farrell (2003a)	Drainage, clearfelling, fertilisation, reforesting
	Aluminium	Cummins and Farrell (2003a)	Drainage, clearfelling, fertilisation, reforesting
		HYDROFOR Project (Kelly-Quinn et al., 2016)	Drainage, fertilisation and afforestation
		Feeley et al. (2013)	Drainage, fertilisation and afforestation
	Calcium	HYDROFOR Project (Kelly-Quinn et al., 2016)	Drainage, fertilisation and afforestation
	Iron	HYDROFOR Project (Kelly-Quinn et al., 2016)	Drainage, fertilisation and afforestation
DOC		Jennings et al. (2009)	Drainage, afforestation
		Feeley et al. (2013)	Drainage, fertilisation and afforestation
		Cummins and Farrell (2003a)	Drainage, clearfelling, fertilisation, reforesting
		HYDROFOR Project (Kelly-Quinn et al., 2016)	Drainage, fertilisation and afforestation
		Barry et al. (2016a)	Drainage, pasture
Acidity		Feeley et al. (2013)	Drainage, fertilisation and afforestation

Rewetting peatlands results in improvements in water quality, although depending on site-specific factors, there may be temporal variations in concentrations. International studies have shown a reduction of pollutants, including nitrate and ammonia, following rewetting compared to drained and degraded peatlands, albeit some rewetted bogs may still have higher concentrations of ammonium compared to natural bogs. While short-term increases in phosphorus have been measured following restoration of nutrient rich peatlands (Harpenslager et al., 2015, Koskinen et al., 2017), studies demonstrate an overall long-term decrease in concentrations (Negassa et al., 2020). Overall, studies show long-term decreases in inorganic nitrogen, phosphorus, base cations, suspended solids and DOC, as well as increasing biodiversity and carbon sequestration potential (Renou-Wilson et al., 2018). There is limited research available on the short- and longer-term effects of rewetting on metal concentrations. It is likely where heavy metal concentrations are higher, they will respond in a similar way to DOC and phosphorus with short-term increases followed by longer-term decreases (Nieminen et al., 2020, Kaila et al., 2016). In addition, rewetting raises and stabilises the water table and increases water retention, as well as reducing infiltration and throughflow, leading to reduced hydraulic conductivity and mobility of pollutants.



A site undergoing peatland restoration. Here, a drain has been blocked with peat dams and the water table is at the peat surface. Photo: David

As peatlands and terrestrial aquatic ecosystems are intrinsically linked, degradation of peatlands can cause deterioration of habitats and reduced levels of biodiversity throughout the catchment, in particular inland waters. Rewetting is associated with increased biodiversity, not just on-site for peatland specific species, but also throughout the catchment, by improving the quality of aquatic ecosystems. The climatic footprint of degraded peatlands is also significantly greater than natural bogs with high carbon dioxide and nitrous oxide emissions (a GHG), particularly for agriculture on reclaimed fenlands or nutrient rich peat. In contrast, rewetted peat soils exhibit decreased emissions.

In summary, drainage and removal of surface vegetation alters water chemistry, as well as hydrology and flow regimes, releasing organic material and nutrients, which degrades inland water quality.

Crucially, rewetting has been shown to be an important management technique to improve water quality, reduce GHG emissions, improve carbon sequestration, and promote biodiversity. As the 'natural' recolonization of peatland vegetation can take some time following rewetting, restoration techniques (e.g. reseeding or transplanting of essential peatland species) can speed up revegetation and produce further improvements in water quality.

2. Carbon cycling of intact, degraded and rewetted peatlands

2.1 Carbon dynamics in natural peatlands

Peatlands play a vital role in regulating the global climate by acting as long-term carbon sinks (Nilsson et al., 2008, Koehler et al., 2011a, Rinne et al., 2020). On average, Irish peat contains 50% carbon on a dry weight basis and holds more than ¾ of total soil organic carbon in Ireland with conservative estimates of 1–1.5 billion tonnes of carbon locked up in the peat (Tomlinson, 2005, Eaton et al., 2008, Cruickshank et al., 1998). Carbon accumulates because the amount of carbon dioxide (CO_2) fixed by the peatland vegetation during photosynthesis is greater than that released during (a) respiration by the plants and the microbial communities, (b) methane (CH_4) emissions, (c) leaching and surface runoff of DOC, (d) losses of POC, and (e) dissolved inorganic carbon (DIC) (Figure 2).

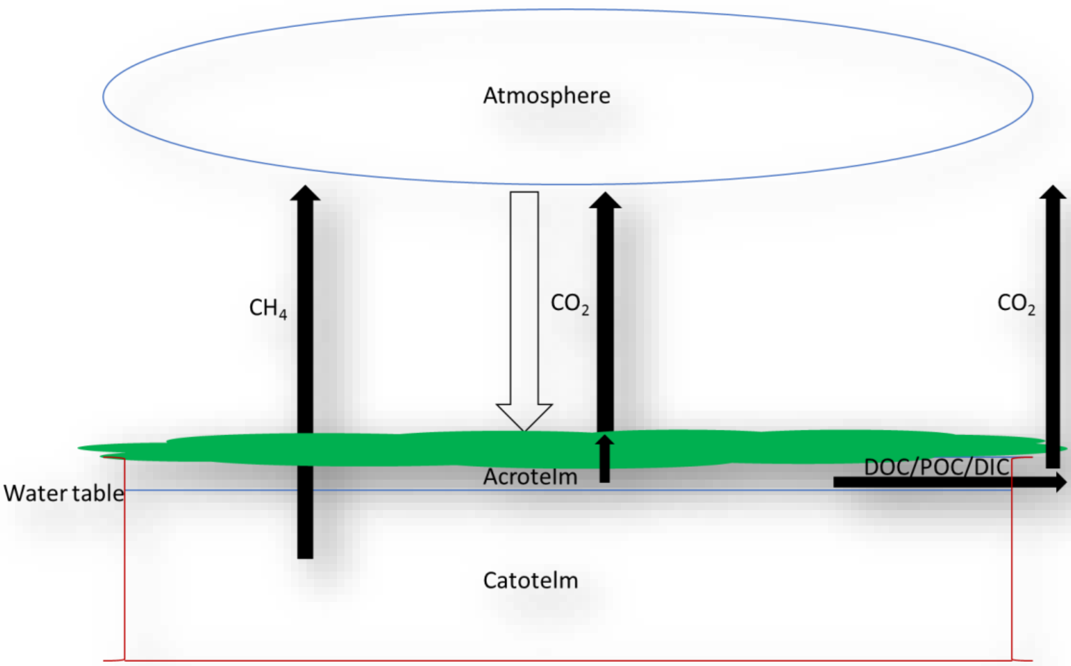


Figure 2: Simplified schematic of carbon dynamics in a natural peatland. Thickness of the arrow indicates the relative strength of the flux. Acrotelm denotes the relatively oxygen-rich layer above the water table, and catotelm denotes the oxygen-poor layer below.

Around 10% of the plant material produced (and the carbon contained therein as a result of photosynthesis and CO_2 uptake) will be deposited below the water table into the oxygen-poor catotelm (Clymo, 1984, Francez et al., 2000) where the rate of decomposition occurs at a much slower rate than decomposition at the surface (Clymo et al., 1998). Over time, the organic matter content (and the carbon contained therein) accumulates and the peatland grows vertically and horizontally (Clymo, 1984). Wetlands account for around 20% of total global methane emissions (Saunois et al., 2020), and natural or near-natural peatlands are a significant source of atmospheric methane. Carbon is also exported fluvially (i.e. waterborne) from peatlands in several forms (Barry et al., 2016b). Dissolved organic carbon (DOC) is commonly the most considerable component of fluvial carbon, and is naturally released from peatlands into streams (Koehler et al., 2009). Particulate organic carbon (POC), however, is considered to be a negligible component of waterborne carbon in natural intact sites (Drösler et al., 2014).

To date, only one near-natural peatland site in Ireland has been monitored over an extended time period for CO_2, DOC and methane (CH_4). This site, located in a blanket bog at Glencar, Co. Kerry, has been found to be an annual CO_2 sink (56 g C/m^2/yr) but an annual source of DOC (14 g C/m^2/yr) and methane (4.1 g C/m^2/yr). These values are similar to other near-natural sites in the United Kingdom.

2.2 Carbon dynamics in degraded peatlands

The vast majority of peatlands in Ireland have been impacted to some extent by farming, peat extraction or forestry (Wilson et al., 2013), all of which require drainage and have various consequences for carbon dynamics (Table 2).

Table 2: Effect of land use change on carbon emissions from Irish peatlands.

↑ = small increase, ↑↑ = moderate increase, ↑↑↑ = large increase, ↓ = small decrease, ↓↓ = moderate decrease, ↓↓↓ = large decrease, ?? = unclear.					
Land use		**Change in C emissions**			
From	**To**	**Management action**	**CO_2**	**CH_4**	**DOC**
Near-natural[1,2]	Industrial peat extraction[3]	Total vegetation removal Intensive drainage Removal of peat	↑↑↑	↓↓	↑
	Domestic peat extraction[3,4]	Partial vegetation removal Indirect drainage Partial removal of peat	↑↑↑	↓↓	↑
	Grassland[5]	New vegetation cover Drainage Fertilisation	↑↑↑	↓↓	↑
	Forestry[6]	New vegetation cover Drainage Fertilisation	??	↓↓	↑
Drained[7]	Restored[7,8]	Drain blocking Rise in water level Plant introduction (possible)	↓↓↓ or ↑↑	↑↑	↓
[1]McVeigh et al. (2014), [2]Koehler et al. (2011b), [3]Wilson et al. (2015), [4]Regan et al. (2020), [5]Renou-Wilson et al. (2014), [6]Drösler et al. (2014), [7]Wilson et al. (2016b), [8]Rigney et al. (2018).					

Drainage, however, has a fundamental impact on the carbon that is stored in the peat and the peatland invariably switches from acting as a long-term CO_2 sink to a large CO_2 source, as well as releasing more waterborne carbon (DOC) (Figure 3).

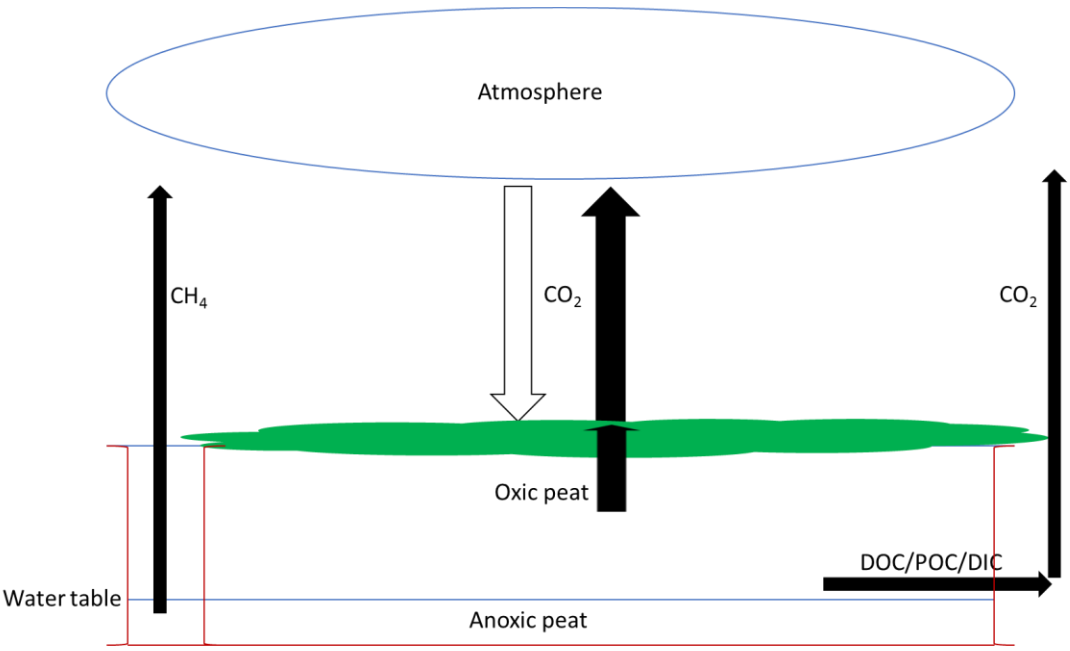


Figure 3: Simplified schematic of carbon dynamics in a drained peatland. CO2 = carbon dioxide, CH4 = methane, DOC = dissolved organic carbon, POC = Particulate organic carbon, DIC = dissolved organic carbon. Thickness of the arrow indicates the relative strength of the flux. Oxygen-rich peat denotes the relatively oxygen-rich layer above the water table, and oxygen-poor peat denotes the oxygen-poor layer below the water table.

Evans et al. (2016) suggests that DOC losses increase by around 60% following drainage. This impacts on water quality, which has implications for the water treatment industry, i.e. increased coagulant costs, increased sludge costs, and fouling of network (Ritson et al., 2016, Jennings et al., 2006). Also, lack of, or inadequate removal of DOC by water treatment followed by disinfection can produce harmful by-products, such as total trihalomethanes (TTHM) (O'Driscoll et al., 2018), which are carcinogenic compounds. Although methane emissions reduce following drainage, drainage ditches may still function as methane hotspots in the wider peatland landscape (Peacock et al., 2017).

2.3 Carbon dynamics in rewetted peatlands

Rewetting has been shown to reduce CO_2 emissions and DOC concentrations (Strack et al., 2014, Wilson et al., 2016a, Evans et al., 2016), although methane emissions are likely to increase (Renou-Wilson et al., 2019, Günther et al., 2020, Wilson et al., 2016b) (Table 2). In some cases, the CO_2 sequestration function characteristic of natural peatlands can fully return (Renou-Wilson et al., 2019, Swenson et al., 2019, Nugent et al., 2018, Wilson et al., 2016b).

2.4 Peatland functioning and climate change

Peatlands are likely to be severely affected by climate change, including changes in decomposition rates leading to a loss of the carbon stored; increased fire risk; and reduced peatland area. For instance, the predicted changes in climate are likely to result in a severe diminution of Irish peatland cover by 2075 (Jones et al., 2006). Indeed, it is projected that more than 50% of the carbon currently stored in Scottish blanket bogs (which exist under the same climate regime as Ireland) could be lost by 2050 (Ferretto et al., 2019). Crucially, the rising temperatures associated with climate change is thought to enhance peatland decomposition and DOC release to inland waters (Dieleman et al., 2016, Worrall and Burt, 2005). Degraded peatlands are also expected to be more vulnerable to climatic changes and importantly, the longer that a rewetted peatland is established, the more resilient it will be to climate change (Renou-Wilson and Wilson, 2018a).

3. Cultural Ecosystem Services and Social values of peatlands

3.1 Overview of cultural ecosystem services concepts and issues

The concept of Cultural Ecosystem Services (CES) provides a means to identify and assess the cultural aspects of an ecosystem's contribution to human wellbeing so they can be included in policy and decision-making alongside provisioning and regulating ecosystem services (Fish et al., 2016). CES have traditionally been defined as the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, cultural heritage, reflection, recreation, and aesthetic experiences, all of which contribute to human health and well-being (Sarukhán et al., 2005). However, cultural services can also provide material benefits, such as income from recreation businesses, provisions from foraging for wild food, or turf cutting linked to social arrangements, such as turbary, all of which have cultural significance (Byg et al., 2017, Waylen et al., 2016). Social values are the values held by individuals or communities in situations or processes, including cultural ecosystem services (CES), such as education, well-being, biodiversity, history and heritage, spirituality, aesthetics, and recreation. Considering social values in decision-making can support transitions to sustainability and enable transformative change and innovative governance approaches (Díaz et al., 2020).

Cultural ecosystem services of peatlands provide important opportunities for recreation, education,

Understanding human dimensions of environmental issues improves conservation and management outcomes (Díaz et al., 2020). Such insights can be applied to minimize conflict between stakeholders; design communication strategies to appeal to people's different values; and understand perceptions of different management decisions (Ives and Kendal, 2014), as well as raising awareness of an ecosystem's value. CES offers a way to incorporate cultural and social values into discussions around sustainable land use, integrated management of catchments, and sustainable management of ecosystems. As demand for cultural services continues to grow in both rural and urban areas (Milcu et al., 2013), the capacity of many ecosystems to continue providing cultural benefits may decrease, unless carefully managed to minimise impacts (Waylen et al., 2016).

Despite their importance, CES are often over-looked in decision-making due to the challenges associated with assessing and valuing them (Dickinson and Hobbs, 2017). Also, there persists a tendency to focus on easily measured CES, such as recreation and ecotourism. And yet, the inclusion of a full range of cultural services is vital to balance the emphasis on monetary valuation and ensure equity and fairness (Hirons et al., 2016, Bullock and Flood, 2020). There are a number of characteristics of CES which make them challenging to assess and value and therefore include in decision making (Table 3).

Table 3: Characteristics of CES which make them challenging to assess and value. Source: Milcu et al. (2013), Dickinson and Hobbs (2017), Kenter (2019) and Waylen et al. (2016).

Characteristics	Challenges
Lack of common terminology & consistent definitions	How to define, value, and measure CES to inform decision making, integrating multiple forms of knowledge and a plurality of values
CES are dynamic	CES vary in different places, and over time, as well as among different individuals and communities
Interconnectedness	Cultural aspects of landscapes are frequently entangled in ways that defy measuring a single service in isolation
Co-produced by people & nature	Reliance on social factors distinguishes them from other ES. Combination of biophysical environment, human perception, & built capital
Intangibility	Makes them complicated but not impossible to measure. Quantitative indicators can be used alongside qualitative and descriptive values
Incommensurability	Some values are not directly comparable having no common unit of measurement or standard of comparison

3.2 Understanding the importance of values

3.2.1 Understanding different types of values

There are different ways of expressing the value of the natural world, which are used in varying ways as justifications for conservation, including:

- Instrumental, intrinsic and relational values

  Environmental value can be defined in terms of instrumental or intrinsic values, that is, the value of protecting nature for human well-being (as a means to an end) versus the inherent value of nature separate from its use to humans (ethical/moral imperative) (Chan et al, 2016). Relational values represent a third dimension of value, which describes the diversity of relationships between people and nature that are conducive to a good life (Chan et al, 2016). There is no clear boundary between these values and so they can be seen as a spectrum.

- Cultural, social and shared values
  Cultural values are shared principles and a shared sense of what is worthwhile and meaningful to people and are derived from the cultural heritage and practices of a society and its institutions (Kenter et al, 2015). Social values are essentially the cultural values and norms of society at large and can be used in a general sense to describe what is important to people and why, while shared values refer to guiding principles and values that are shared by groups or communities (Kenter et al, 2015).

3.2.2 Methods for incorporating social and cultural values

There are a variety of monetary and non-monetary methods for valuing and measuring CES, alongside approaches which prioritise co-production of knowledge and social learning (Hirons et al, 2016). While economic methods have raised awareness of environmental benefits, they have failed to achieve significant change in policies and are not considered adequate for describing many cultural services (Bullock, 2020). Increasingly, mixed methods research, which integrates both qualitative and quantitative evidence is advocated, alongside participatory, place-based approaches.

3.3 Cultural ecosystem services of Irish peatlands

Currently in Ireland, there is a shift in cultural values and societal norms around the uses and value of peatlands. Traditionally, economic and utilitarian values relating to extraction of peat had the most value for companies like Bord na Móna and communities living beside peatlands. However, cultural aspects, such as recreation, tourism, and heritage are increasingly considered of value by emerging community groups as peatlands transform from being sites of labour and employment to sites of restoration, recreation, and conservation (Bullock and Flood, 2020). These shifts in values from unsustainable extraction of peat to management for biodiversity and ecosystem services, are largely positive and supportive of sustainable peatland management.

Critically, wider political and societal support is needed to improve awareness and understanding of the multiple values of peatlands and to halt ongoing unsustainable extraction, such as that associated with the horticultural peat industry. Raised awareness of societal values is increasingly reflected in public policy debates, such as those around (cessation of) turf cutting, industrial peat extraction, and planting forestry on peat soils. There is evidence that people living in communities around industrial peatlands wish to participate in conversations around their future, with strong support for amenity and biodiversity after-uses in evidence (Collier and Scott, 2008). The measurement and valuation of CES can create cultural change and redefine social norms around the values of peatlands and their use for the common good rather than for private economic gain.

Reflecting wider trends, Irish research on peatland ecosystem services has tended to focus on provisioning and regulating services of peatlands, including water quality, carbon stocks, and flood attenuation (e.g. SWAMP and AUGER projects). Relatively little research activity has focused directly on cultural services of peatland ecosystems. The NPWS Mapping and Assessment of Ecosystem Services (MAES*)* report (Parker et al., 2016) highlighted the challenges in measuring cultural aspects of ecosystems and recommended further research on CES in Ireland.

The valuation of ecosystem services has multiple applications in supporting decision making, whether as part of natural capital accounting projects (e.g. the INCASE project); more generally to raise awareness; as a tool for stakeholder dialogue and engagement; or to inform payments for ecosystem services and agri-environment schemes relating to peatlands. The integration of cultural and social values in these processes is important to ensure well-informed decisions are made about trade-offs between different management approaches, and all costs and benefits are taken into account. Table 4 provides an overview of policy and plans relating to CES and offers a starting point for a more in-depth analysis of the policy landscape and how it intersects with cultural ecosystem services in Ireland.

Table 4: Sample of policy and plans relating to CES and social values of peatlands.

Sector	Policy / Strategy	Related cultural services and values
Peatlands	Bogland report, 2011	Cultural heritage preservation; Landscape and recreation; Peat as a resource - source of energy, horticulture, cultural tradition & recreation
	National Raised Bog SAC Management Plan 2017 – 2022	
	National Peatlands Strategy 2015	
Heritage	Heritage Ireland 2030 County Heritage Plans	Cultural and natural heritage, history, aesthetic, and place-based values
	The Ramsar Convention on Wetlands of International Importance (1972) - Culture & Heritage working group	Traditional and local knowledge; cultural tradition, practices, and heritage; non-material customs/values
	Culture 2025 – A National Cultural Policy Framework to 2025	Cultural heritage and the arts
Biodiversity	National Biodiversity Strategy 2017 - 2021	Biodiversity which underpins all ecosystem services

Health and Wellbeing	Healthy Ireland Strategy 2013 - 2025	Recreation, Nature-based activities, Social relations
Recreation & Ecotourism	Outdoor recreation plan for public lands and waters in Ireland 2017-2021	Recreation, Nature-based activities, Ecotourism
	People, Place & Policy: Growing Tourism to 2025	
Education & Training	National Strategy on Education for Sustainable Development 2014-2020	Formal and informal education, Nature-based activities
	National Policy Framework for Children and Young People	
Landscape	National Landscape Strategy 2015-2025	Cultural and natural heritage; education; research; recreation and ecotourism; sense of place

4. Alternative management options of degraded peatlands

The evaluation and application of innovative technologies and alternative management options for degraded peatlands to improve water quality, whilst enhancing other peatland ES, should consider the existing land use and the sensitivity and vulnerability of the surface water and groundwater receptor. This section outlines the range of current and alternative management options available for three main peatland uses: extraction, commercial forestry and agriculture.

4.1 Extracted peatlands

Current management practices and mitigations for peat extraction include silt ponds, rehabilitation, and reclamation for new land uses. Silt ponds, in particular, target suspended sediment and do not consider other contaminants, such as ammonium which enters aquatic ecosystems downstream of peat extraction sites.

Silt pond at peat extraction site. Photo: Florence-Renou Wilson.

Rehabilitation involves allowing a site to naturally recolonize with vegetation to stabilise the bare peat surface and minimise pollution to air and water. Rehabilitation forms part of the requirements of decommissioning and licence termination, and monitoring verifies no outstanding environmental liability. Rewetting is not required under licencing for rehabilitation and revegetation occurs through natural succession. Typically, vascular plants rather than bog indicator species return, even after a 30-year period. Alternatively, the Enhanced Rehabilitation Scheme, which prescribes increasing the water table to within 10 cm of the surface and additional interventions, offers the most long-term water quality benefits, in addition to climate change and biodiversity benefits.

Where unfavourable site modifications could not support rewetting, new habitat types, i.e. mosaics of bog/ fenland, woodland, heather and scrub/ open water are proposed. In cases where pollution is likely to remain an issue, additional techniques can offer potential for water quality improvements and include biochar filters, overland flow, constructed wetlands and chemical purification. Overland flow involves diverting runoff to a vegetated area, which has the additional benefits of particle trapping and nutrient uptake by the vegetation. Constructed wetlands may be an option where land

An extraction site which has been flooded to create an area of wetland. Photo: Catharine Pschenyckyj.

is not available for overland flow, and have been shown to purify extraction runoff thereby reducing nutrients and suspended solids, carbon sequestration, production of biomass, and the promotion of biodiversity. Chemical purification shows promise for immobilising P and removing DOC and suspended solids in peatlands. Biochar is capable of absorbing organic and inorganic nutrients, heavy metals and other contaminants. Finally, a trial study in the Irish Midlands concluded that industrial cutaway peatlands were not suitable for raw water storage as reservoirs due to sub-peat geological and hydrological properties of the remaining peat.

4.2 Commercial forested peatlands

Multiple interventions have been suggested for afforested peatlands, but guidelines are lacking when it comes to providing a clear decision-tree for the intervention selection process, which should be based on scientific data that can provide pollution prevention solutions in catchments with sensitive receptors. Best Management Practices (BMP) established for forestry operations on peatlands are derived from those in existence elsewhere, and so are not site-specific or scientifically robust and result in pollution events following clearfelling. Novel practices that should be considered include retrofitted buffer zones/overland flow systems, whole tree harvesting, continuous cover forestry (CCF), and a refinement of the use of brash mats. CCF may be advantageous in sensitive catchments because of reduced risk of windthrow, reduced soil carbon losses to air and water, better soil fertility levels, and reduced water table fluctuations. It is not clear whether CCF could be a sustainable option for peatland forestry in the west due to windthrow. Grass seeding could be used to enhance the natural regeneration process in a clearfelled catchment thereby accelerating P uptake and reducing P export. Biochar filters have been used to purify runoff from clearfelled forests in other countries and are currently being tested in Ireland. Also, exhausted biochar can be applied to newly afforested sites as a soil amendment that would slowly release nutrients back into the soil for the newly planted trees (Köster et al., 2020, Zhao et al., 2019). Restoration of afforested peatland sites has highlighted the challenges involved in returning the ecosystem services of the bogs. Alternative replanting models could offer more optimistic outcomes but needs long-term monitoring.

With multiple possibilities for afforested peatlands, a clear decision-tree with guidelines for future management options is warranted with BMP based on scientific quantitative data that can provide pollution prevention solutions for afforested peatlands in catchments with sensitive receptors and identified by the Register of Protected Areas (i.e. incorporating areas requiring special attention under existing national or European legislation, i.e. drinking water, shellfish and freshwater fish, recreational waters, nutrient sensitive areas and areas protected under the Birds Directive and Habitats Directive. Ideally, a decision-tree for afforested peatlands should consider three key pillars, which will determine the future management of sites:

A recently clearfelled Sitka Spruce plantation on peatland. Photo: Catharine Pschenyckyj.

1) Carbon management: whether a second rotation will create a net GHG sink, sufficient to offset what would be lost during cultivation, and whether additional cultivation or nutrients would be required?
2) Is the coupe in a drinking water protected area?
3) Is the coupe within the zone of influence of an ecologically sensitive receptor?

4.3 Agricultural peatlands

A peatland pasture with grazing sheep. Photo: Connie O'Driscoll.

Research has shown that the environmental impact of peatlands used for agriculture depends on drainage history, peat type and water table management. Large GHG and DOC emissions from drained nutrient rich peat under grassland must be targeted for water table management to mitigate climate change in the agricultural land use sector. Rewetting of nutrient poor organic soils with poor drainage, coupled with grazing reduction, has demonstrated benefits for carbon cycling processes (Renou-Wilson et al., 2015). Also, European Innovation Partnership (EIP) locally led Schemes, such as the Pearl Mussel Project (https://www.pearlmusselproject.ie/) or the Hen Harrier project (http://www.henharrierproject.ie/), are supporting farmers in developing innovative approaches to agriculture that aim to reduce environmental impacts and, therefore, enhance habitats for sensitive receptors. Examples include targeted fencing, strategic positioning of drinking troughs, light grazing regime, rewetting utilising peat plugs and flow reduction via timber weirs. Development of quality habitat and vegetation is being promoted in the EIPs and has a direct impact on water quality downstream, reducing suspended sediment and nutrients.

As agricultural peat soils are one of the largest peatland land use categories, it is critical to develop strategies to reduce carbon emissions to the atmosphere and to the water, which are tailored to local grassland types and climates.

5. Strategic guidance and resources for future integrated management of peatlands

This final work package considers approaches to help meet the environmental challenge of managing our peatlands sustainably so that threats to water quality (surface and drinking), climate and other ES (biodiversity etc.) are reduced. With the overall aim to optimise water quality returns from peatland management, while delivering co-benefits for climate and biodiversity, strategic guidance and resources are detailed below, which could be incorporated into future changes in land use and sustainable peatland utilisation. Four priorities have been identified and within these, solutions have been provided or key actions have been suggested.

Priority 1- Include social values in peatland management and enhance stakeholder collaboration

Aim: To enable social values and perspectives to be identified, assessed and included in peatland management and decision making, and lift barriers by enabling collaboration between stakeholders.

☞Incorporate social and cultural values into research, policy, and decision-making

- Interdisciplinary and transdisciplinary research:

  R 1.1*: Encourage the inclusion of research from social sciences, humanities, and the arts alongside economic and ecological disciplines when commissioning research to guide conservation and sustainable management of peatlands.*

- Co-production of knowledge:

  R 1.2*: Develop shared knowledge of different areas of expertise at all stages of projects and co-develop research objectives, methods and outputs from the start.*

☞Identify evidence gaps and encourage research on Cultural Ecosystem Services (CES) and social values of peatlands

- Data, inventories, and monitoring of CES of peatlands:

R 1.3*: Identify potential data sources to support mapping of CES of peatlands and generate new sources where necessary.*

- CES Indicators:

  R 1.4: Identify suitable indicators for CES of peatlands so results of assessments and valuations can be communicated to decision makers and practitioners in conservation management.

- Research on the impact of restoration, rewetting, or ongoing degradation of peatlands on the provision of cultural services:

  R 1.5*: Identifying whether the ecological state of peatland ecosystems positively or negatively affects the delivery of cultural services, and differences in provision of CES in different types of peatland habitat e.g. coastal blanket bogs, raised bogs and industrial cutaway.*

☞Enhance collaboration with all stakeholders

Established organisations with the power to facilitate networking and knowledge sharing should be identified and tasks with specific remit in order to contribute to the delivery of the key recommendations below.

- Collaboration between stakeholders:

R 1.6: A map of Irish peatland stakeholders has been initiated and should be published and shared with the public as a basis for further stakeholder analysis and improved collaboration: the map is available here for comments: https://adobe.ly/3uaAfQV

R 1.7*: Conduct a stakeholder analysis to identify key collaboration pathways, assess the quality of stakeholder relationships and recommend new areas for collaboration.*

R 1.8*: Create new and support existing networks and bridging organisations.*

R1.9*: Ensure meaningful engagement and participation early in the collaborative process.*

R1.10*: Stakeholders should engage in collaborative actions including awareness raising; advice, training, and knowledge transfer; and building a common platform, such as a National Peatland Group.*

- Stakeholder research collaboration:

  R 1.11*: Priority should be to widen the sources of funding in order to establish long-term monitoring, which is typically lacking around restoration projects as funded research projects are* *always limited in time. Funding for researchers to train communities and practitioners is critical to enable transfer of skills, as well as efficiently communicating the science to the public. Finally, a new model of co-designed research that integrates citizen science must be developed to provide a bottom-up, place-based perspective to peatland research.*

☞Develop mechanisms to support inclusive and collaborative governance and encourage bottom-up approaches to integrated peatland management

The following recommendations can help to support sustainable management of peatlands at community level:

***R 1.12**: Build local community capacity in understanding, monitoring and assessment of peatlands through training, citizen science initiatives and knowledge exchange.*

***R 1.13**: Develop structures and supports for community groups applying for funding.*

***R 1.14**: Develop strong partnerships between state agencies and community groups and networks in an open, transparent, two-way process of information sharing. The Community Wetlands Forum provides a platform and advice for developing such partnerships, and Public Participation Networks (PPN) could also be better utilised to provide guidance and funding to community environmental groups.*

***R 1.15**: Encourage public sector organisations to have dedicated community liaison staff with expertise in community engagement and knowledge of participatory approaches to conservation.*

***R 1.16**: Encourage action research approaches, i.e. research that is initiated and driven by communities, and where communities are involved with researchers in all aspects of the research process.*

***R 1.17**: The need for integrated rather than single-value approaches to ecosystem assessment and valuation, which combine ecological, cultural, economic, and ethical value dimensions, is increasingly advocated* (Díaz et al., 2020, Jacobs et al., 2016).

Priority 2- Identify land use/ land use change impacts and co-benefits of management options

Aim: to provide an accurate understanding and coherent vision of peatland utilisation, their impacts and the available choices.

☞Embed each peatland management decision within an overview of peatland utilisation options, impacts and co-benefits

> ***R 2.1:*** *It is recommended to identify and disseminate scientific facts about peatlands pertaining to each management decision in order to provide a coherent vision of the range and extent of peatland utilisation and known impacts on key ecosystem services, such as climate, biodiversity, water and socio-cultural (Table 5).*

While we have aimed to target specific land use and specific issues with the most appropriate potential mitigation measures, the guidance is not overly prescriptive, as each peatland site is different. Successful rewetting of degraded peatlands is a major challenge and, in some cases, may be a balancing act between biodiversity, climate and socio-economic benefits (Renou-Wilson et al., 2019, Renou-Wilson and Wilson, 2018b).

Table 5: Peatland land use and land use change impacts on ecosystem services (ES). Icons represent positive, negative and no change. An action can have both positive and negative impacts.

Land use		**Management**	**Ecosystem Services**			
From	To	Management action	Climate	Biodiversity	Socio-cultural	Water
Natural	Natural	➢ Full protection	👍	👍	👍	👍
	Industrial peat extraction	➢ Total vegetation removal ➢ Intensive drainage ➢ Removal of peat	👎	👎	👎	👎
	Domestic peat extraction	➢ Partial vegetation removal ➢ Indirect drainage ➢ Partial removal of peat	👎	👎	👍 👎	👎
	Grassland	➢ New vegetation cover ➢ Drainage ➢ Fertilisation	👎	👎	👍 👎	👎
	Forestry	➢ New vegetation cover ➢ Drainage ➢ Fertilisation	👎	👎	👍 👎	👎

Drained	Restored	➢ Drain blocking ➢ Rise in water level ➢ Plant re-introduction	👍	👍	👍	👍
	Rewetted only	➢ Water table management	👍	👍 ☞	👍	👍
	Paludiculture (wet agriculture or forestry)	➢ Water table management ➢ Wet species	👍	👍	👍	👍
	Shallow drained grassland	➢ Water table management	☞	☞	👍	☞

Priority 3- Implement existing policies and ensure full compliance with relevant regulations

Aim: to prevent deterioration of water quality and apply adequate mitigation measures. The case for the sustainable integrated management of peatlands is underpinned by existing legislation whose compliance directly bears on the development and outcome of the sustainable management of peatlands. Compliance with existing regulations with the eradication of deficiencies or conflicts in these legislations must be improved as a first approach to integrated peatland management in Ireland, and recommendations in relation to different types of governance is presented below.

☞Conservation/biodiversity governance

R 3.1*: To urgently meet the objectives for designated protected peatlands under the Habitats Directive and restore all raised and blanket bogs SAC.*

R 3.2*: To provide sufficient funding via new funding mechanisms for peatland restoration schemes, which include long term monitoring, support for peatland community schemes and promotion of citizen science.*

☞Environmental governance

***R 3.3**: Finalising the legal status of all peat extraction activities together with the implementation of evidence-based mitigation measures.*

☞Agricultural and forestry governance

***R 3.4**: Rewetting of nutrient rich organic soils that act as hot spots of both CO_2 and N_2O should be prioritised.*

***R 3.5:** Incentives are required to rewet agricultural peat soils.*

***R 3.6**: Ireland must look at the combination of new CAP instruments that are now available, which could pave the way toward low-emission peatland utilisation to satisfy the need of a range of stakeholders.*

***R 3.7**: Decisions on future land use must be site-specific accounting for the full suite of ES and demonstrate a clear regard for sensitive receptors.*

☞Water governance

***R 3.8**: Peatland degradation status should be fully recognised in the River Basin Management plans and thus monitored carefully in all catchments, especially with regards to DOC and ammonia emissions within each catchment.*

Priority 4- Investigate the current and future risks; monitor actions; and research alternatives

Aim: to identify gaps in knowledge, monitor existing projects and research alternatives to better inform decision

☞Environmental and land use research

R 4.1: Key research questions pertaining to land use and land use change affecting peatlands including windfarms, forestry and agriculture should be carefully scoped out, compiled and prioritised.

R 4.2: An Ecosystem Approach (used to improve ecological impact assessment) should be called upon to set up the next research priorities in relation to peatlands.

☞Long-term monitoring and datasets repository

***R 4.3**: Tracking the success of interventions for integrated peatland management (e.g. long term monitoring of key performance indicators following rewetting schemes) is critical to develop robust guidance.*

***R 4.4**: As a priority, a compendium of Irish restoration/rewetting projects and peatland datasets should be available to all stakeholders.*

***R 4.5**: Development of a standardised methodology and training capacity that enables individual peatland sites to be consistently monitored, thereby creating a network of comparable sites.*

***R 4.6:** Establish a national peatland observatory / research site network to support long-term research and initiate large scale pilot studies/catchment interventions; in conjunction with a common research protocol (definition, field measurements etc.).*

☞Innovative sustainable management options

***R 4.7:** New, well-designed experimental field studies with replications should be established at various cutaway and cutover bogs across the country with suitable varied environmental characteristics, in order to trial wet cultivation techniques (paludiculture).*

Resources

Financing integrated sustainable peatland management should be a long-term policy. The priority lies with the blanket bog SAC/SPAs, as well as the remaining raised bog SACs that have not been restored to date. Costs are difficult to calculate with precision, but the cost of not restoring the network of protected raised and blanket bogs can be alternatively estimated via proxies, adding the amount CO_2 emitted (~ 4-6 million tonnes of CO_2eq each year), the cost of cleaning pollutants from surface and drinking water, the cost of lost biodiversity etc. **Governmental support to provide funding under the Habitats Directive regulations is unequivocal and perpetual. There is need for government bodies to carry out a full economic analysis of these requirements.** Such economic analysis is a key priority to obtain a coherent vision of how and why the Irish peatland resource should be managed in such an integrated fashion.

As a second stream of resources to finance the sustainable management of peatlands, we have identified results-based agricultural payment schemes as a critical instrument to set attractive incentives for reducing GHG emissions and for supplying other ES. Additional feasibility studies must be deployed beyond the Midlands to identify barriers associated with agricultural peatlands in the west of Ireland in particular. LAWPRO, Teagasc and the An Fóram Uisce have a role to play here in not only **informing the relevant stakeholders but also in the long-term monitoring.** Thus, staff and funding within these institutions should be identified not only for direct involvements in projects but also as an advisory capacity.

As peatlands are rarely in single-ownership, integrated management of peatlands requires special attention extended to communities living around the bogs. While national funding opportunities are available for communities, it is critical that t**he government provide a long-term financial framework to secure the continuity of the sustainable management of shared peatland resources.** Peatland community schemes (DAHG) must support communities living around bogs (not just the designated ones) in the west of Ireland (not just in the Midlands) and who have strong economic (tourism) and cultural incentives to manage their peatland resource.

Finally, **innovative funding mechanisms are needed.** While a number of large EU and state funded projects are on-going and due to start in 2021, vast areas of peatlands require financial intervention from other sources. Remunerating ES, especially a carbon credit scheme must be developed. Such a scheme would provide a mechanism by which businesses, organisations and individuals could invest in land-management and restoration schemes that would deliver GHG reductions or removals, delivering financial support to farmers and others to adopt sustainable land-management practices, undertake restoration and increase the extent of ecologically valuable habitats. While further data is required for certain land uses and geographical regions to support carbon credit schemes, **an initial assessment of the maximum carbon offset potential from Irish peatlands should be established.** It is predicted that carbon offsetting schemes would not only have the potential to deliver significant climate change mitigation, but would also support habitat conservation, provide cleaner water, and generate new sources of income for farmers/ landowners.

Conclusion

This scoping report has focused on integrating and synthesising the scientific information needed to provide recommendations for management of Irish peatlands to optimise water quality, alongside co-benefits for other ecosystem services. It highlights the extent of damage to Irish peatlands and the knock-on impacts to other aspects of the environment, including water quality, carbon cycling and biodiversity. In addition, a thorough review of cultural ecosystem services has enabled evidence gaps to be identified, and guidance is provided on how best to elicit, assess, and include the wide range of values and perspectives for sustainable peatland management and decision making.

Current and alternative management options for different peatland uses (extraction, forestry and agriculture) are reviewed in terms of effectiveness based on best available knowledge, and knowledge gaps are highlighted. Given the degraded status of most Irish peatlands, the rewetting (first step in a range of management options ranging from wet cultivation to full restoration of peatlands) is the only management option that can deliver the full suite of ecosystem services associated with healthy peatlands (Figure 4).

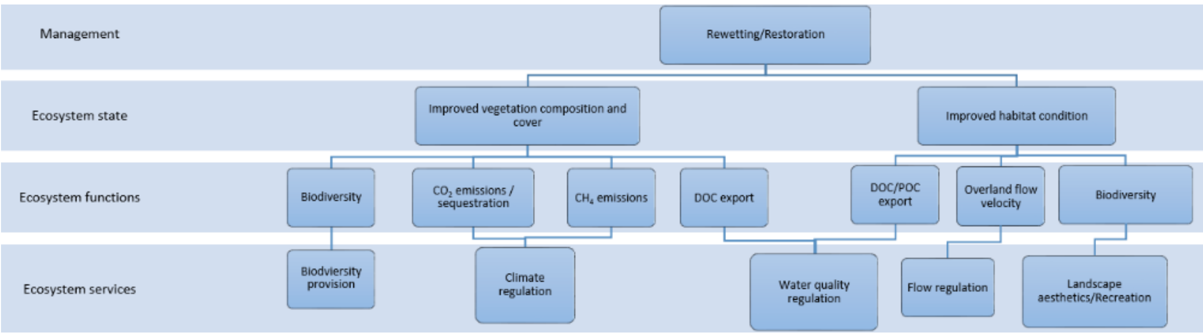


Figure 4: Schematic of impact of rewetting/restoration of a peatland on its states, ecosystem functions and ecosystem services.

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