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Identifying pressures • Informing policy • Developing solutions

Network Monitoring Rewetted and Restored Peatlands/Organic Soils for Climate and Biodiversity Benefits (NEROS)

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

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Cover images: Top left – static dark chambers used to measure methane from permanent sample plots at Blackwater rewetted bog (photo: David Wilson). Bottom right – sundew (*Drosera rotundifolia*), a carnivorous plant found at Sopwell rewetted bog (photo: Flo Renou-Wilson). Main picture – Moyarwood rewetted bog (photo: Flo Renou-Wilson).

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Natural peatlands are a high priority for biodiversity conservation, as species and habitats of international importance depend on the waterlogged conditions. Rewetting of drained peatlands and organic soils aims to return these conditions and set the system on a trajectory that will lead to biodiversity levels characteristic of natural peatlands. In addition, future land use of rewetted peatlands and organic soils should contribute to the reduction of greenhouse gas (GHG) emissions, being in line with not only climate change conventions but also sustainability demands (Renou-Wilson *et al*., 2011).

This report is opportune, as it informs on the delivery of sustainable management of one of the last natural resources in Ireland, as envisaged in the National Peatlands Strategy, as well as facilitating legal requirements under many European Union (EU) directives, notably the Habitats Directive, the Birds Directive, the Water Framework Directive and the Landscape Directive, as well as aiding in the mitigation of climate change impacts.

This report describes a field-based study that simultaneously quantified both biodiversity and climate mitigation benefits (i.e. GHG fluxes) across a rewetted peatland land use category network (NEROS). The land use categories (LUCs) monitored were forestry (on nutrient-poor soils), grassland and peat extraction (domestic cutover and industrial cutaway on nutrient-poor and nutrient-rich soils). Drained sites were also monitored for comparison purposes.

We found that the flora of the rewetted/restored bogs was very similar to that of their natural counterparts in sites where initial drainage was the only disturbance. Both raised and blanket bogs that have been drained (but not planted or cut) also exhibited the expected range of micro-habitats and species composition. On the other hand, increased numbers of species and/or macro-habitats was a negative indicator of restoration/ rewetting projects in large and heterogeneous sites such as industrial cutaway peatlands.

In the case of forested peatlands, site conditions prior to rewetting/restoration (dry forest soil) and methods utilised (leaving brash/felling material on site) strongly influenced the recovery of micro-habitat heterogeneity and indicator species such as bryophytes.

The excellent cover of *Sphagnum* moss at the studied rewetted raised bog is a promising indicator. However target species identified in high-conservation-value raised bogs are still rare or absent from the rewetted sites. It is critical that diverse *Sphagnum* species colonise these rewetted sites not only for biodiversity but also to return the carbon (C) sequestration function of the bog.

The drained sites were net sources of carbon dioxide (CO_2), with emissions highest in the nutrient-rich industrial cutaway LUC (mean: $1.51\,t\,C\,ha^{-1}\,yr^{-1}$), followed by domestic cutover (mean: $1.37\,t\,C\,ha^{-1}\,yr^{-1}$), nutrient-poor industrial cutaway (mean: $0.91\,t\,C\,ha^{-1}\,yr^{-1}$) and grassland (mean: $0.81\,t\,C\,ha^{-1}\,yr^{-1}$). Drained sites were not monitored in the forestry LUCs. Methane (CH_4) emissions were low at the drained sites and ranged from 0 to $15\,kg\,C\,ha^{-1}\,yr^{-1}$. Nitrous oxide ($N_2O$) fluxes were not detected.

The rewetted nutrient-poor industrial cutaway (mean: $-1.04\,t\,C\,ha^{-1}\,yr^{-1}$), domestic cutover (mean: $-0.49\,t\,C\,ha^{-1}\,yr^{-1}$) and grassland (mean: $-0.40\,t\,C\,ha^{-1}\,yr^{-1}$) LUCs were net sinks of CO_2, while the nutrient-rich industrial cutaway (mean: $0.32\,t\,C\,ha^{-1}\,yr^{-1}$) and forestry (range: 1.02 to $5.60\,t\,C\,ha^{-1}\,yr^{-1}$) LUCs were net sources. CH_4 emissions were highest in the domestic cutover LUC (mean: $197\,kg\,C\,ha^{-1}\,yr^{-1}$) followed by nutrient-rich industrial cutaway (mean: $173\,kg\,C\,ha^{-1}\,yr^{-1}$), nutrient-poor industrial cutaway (mean: $92\,kg\,C\,ha^{-1}\,yr^{-1}$), grassland (mean: $44\,kg\,C\,ha^{-1}\,yr^{-1}$) and forestry (range: $20–26\,kg\,C\,ha^{-1}\,yr^{-1}$).With the exception of the forestry LUCs, N_2O fluxes were not detected or were negligible.

Overall, in regard to biodiversity, the study demonstrated that environmental and management variables can influence species composition and therefore regeneration of typical species of natural sites (biodiversity indicators of rewetted and restored peatlands). The same variables together with the vegetation composition will indicate whether

or not the GHG emissions can be reduced and the biogeochemical functions returned to those characteristic of natural peatlands. By fully exploiting the synergy potential of the climate change–biodiversity nexus, rewetting and restoring degraded peatlands and organic soils can help to maximise their biological potential in terms of biodiversity and associated functions and therefore deliver a range of ecosystem services usually attributed to non-degraded peatlands.

This study has highlighted the climatic benefits from rewetting degraded peatlands in terms of reduced GHG emissions, the return of the C sequestration function characteristic of natural (non-degraded) peatlands in many cases, and increased biodiversity provision. However, rewetting of degraded peatlands is a major challenge and can be a balancing act between benefiting biodiversity and/or climate. We recommend that the degraded peatland LUCs monitored in this study should be prioritised in terms of rewetting in the following order, to maximise biodiversity provision and climate change mitigation, and taking full cognisance of the potential areas of each LUC.

1. Rewetting drained-only and domestic cutover areas

- *Benefits*: high biodiversity provision, high CO_2 emissions avoided, high areal coverage (Table 2.1).
- *Disadvantages*: moderately high CH_4 emissions, potential costs involved in rewetting, difficulty in maintaining a high water table in some sites.

2. Rewetting grassland areas

- *Benefits*: modest biodiversity provision, high CO_2 emissions avoided, paludiculture options, high areal coverage (Table 2.1).
- *Disadvantages*: moderate CH_4 emissions, potential costs involved in rewetting, difficulty in maintaining a high water table in some sites.

3. Rewetting industrial cutaway areas

- *Benefits*: high CO_2 emissions avoided, paludiculture options, medium areal coverage (Table 2.1).
- *Disadvantages*: low biodiversity provision (but potentially new ecosystem diversity), moderate CH_4 emissions, difficulty in maintaining a high water table in some sites.

4. Rewetting afforested areas

- *Benefits*: modest biodiversity provision, medium areal coverage.
- *Disadvantages*: high CO_2 emissions, priming effects from brash decomposition, moderate CH_4 emissions, potential N_2O emissions, difficulty in maintaining a high water table in some sites.

Final Observations and Recommendations

- **Observation 1**: Long-term monitoring of GHG emissions from the NEROS network sites demonstrated that drained peat soils are significant hotspots of CO_2 emissions, which in turn are strongly controlled by soil temperature, water table level and vegetation composition. These data also expand our national GHG dataset and contribute to the reporting of GHG emissions from managed peatland LUCs at Tier 2 reporting levels.
- **Recommendation 1:** Since drained peatlands managed for peat extraction are significant CO_2 emission hotspots and have a positive feedback effect on climate change (with a probable increase in CO_2 emissions with projected increasing temperatures), they should be targeted for rewetting as a climate change mitigation strategy.

- **Observation 2:** Within the NEROS network of rewetted sites, rewetting actions (drain blocking) have been highly successful in raising the water table to close to or above the soil surface, even in the most degraded ecosystems. Maintaining high water table levels is a challenge across large sites (e.g. thousands of hectares of industrial cutaways) and for sites with little potential to establish dams (e.g. elevated dry sites). Moreover, seasonal and inter-annual variations in water table levels still prevail, depending on weather conditions, but are buffered by certain vegetation types.
- **Recommendation 2:** While each rewetted site brings its own challenges, rewetting methods should be developed and implemented after careful site assessment. In all cases, the primary effort should be in the preparation of the site to raise the water table and keep it close to the surface; this is critical for the successful return of hydrological functioning within a peatland.

- **Observation 3:** Rewetting can bring back peat-forming vegetation within a short timeframe (< 10 years) and this period is shortened in less damaged sites, such as drained-only raised bogs. Vegetation species most characteristic of intact raised bogs are present to some degree on such sites (subject to modest degradation), and rewetting actions (drain blocking) have been highly successful in raising the water table to close to or above the soil surface and crucially maintaining it at high levels over time.
- **Recommendation 3**: Drained-only sites or bogs that have suffered only modest cutting on the margins should be priority sites for rewetting activities to bring back the unique biodiversity associated with such ecosystems.

- **Observation 4**: Rewetting can provide benefits in terms of reducing GHG emissions for climate regulation, and the long-term monitoring in this study has demonstrated that it is a rapid strategy to mitigate climate change by either decreasing high CO_2 emissions or, for the better sites, returning the C sequestration function characteristic of natural bogs. However, this capacity clearly depends on site characteristics and not only on previous land use management.
- **Recommendation 4:** Nutrient-poor organic soils (under either peat extraction or grassland) have been identified as priority sites that can provide the greatest benefits not only in terms of reducing GHG emissions relative to their drained state but also with the potential to sequester C in the long term.

- **Observation 5**: In the NEROS network, we have identified "drained-only bogs" as the most optimal rewetted site type, which provide benefits for both biodiversity and climate regulation.
- **Recommendation 5**: With high biodiversity provision, avoided CO_2 emissions and high areal coverage, drained-only sites, which include most domestic cutover bogs (where a significant area of high bog remains), should be targeted for rewetting so that Ireland can deliver on both biodiversity and climate targets and to facilitate its legal requirements under EU directives and international conventions.

- **Observation 6:** Difficult sites have been identified within this study where rewetting has failed to return the ecosystem functions, be it in space or in time. This was because the site might be very large and heterogeneous, for example large industrial cutaway peatlands. Rapid large-scale rewetting can permit a mosaic of habitats, which may not all be C sinks but will contribute to biodiversity. Another challenge to a quick return of natural ecosystem functions may arise if there is an intensive change in environmental conditions (e.g. the site was dry for a long time) or if the site includes material from previous land use, for example the brash left in rewetted clear-felled forestry sites, which leads to increased CO_2 emissions to the atmosphere as well as via aquatic pathways.
- **Recommendation 6:** In the case of large industrial cutaways, rehabilitation projects aiming to re-establish vegetation on stabilised peat should take cognisance of future possible rewetting options (in the short and long term). This requires on-going monitoring of both hydrology and vegetation dynamics to evaluate the need for additional work to correct undesired successional and hydrological outcomes. Similarly management of rewetted clear-felled forested peatlands should ensure that necessary interventions during the early years after initial rewetting/restoration works include (1) the regular monitoring of water table levels, (2) the appropriate management of the catchment to maintain water table levels close to the surface, and (3) the removal of all felled material (brash) from rewetted/restored forestry sites.

- **Observation 7:** Peat soils cover more than 20% of the country and so far rewetting/restoration has been confined to the designated network of raised bogs. A national strategy for rewetting *all* types of degraded peatlands should be established to select the best sites to maximise a reduction in C losses and potential for C sequestration and to increase biodiversity benefits. This requires information on biological and physical attributes, management regimes, conservation objectives if present, etc., as well as local knowledge from all stakeholders.

- **Recommendation 7**: High-resolution maps of Irish peatlands under various management/land uses and disturbance regimes, showing their current characteristics and rewetting/restoration potential should be developed to target priority sites for biodiversity and/or climate benefits. Meanwhile a database of all rewetted/restored peatlands and organic soils in Ireland should be established by collating all available monitoring data.

1 Introduction

1.1 Background

1.1.1 Peatlands, a unique natural resource

Ireland contains large areas of wetlands that constitute some of the most ecologically diverse habitats in the country (Otte, 2003). Peatlands are the main subclass of wetlands and cover between 14% and 20% of the territory (Hammond, 1981; Connolly and Holden, 2009). In natural (i.e. not degraded) peatlands, permanently waterlogged conditions prevent the complete decomposition of dead plant material leading to the accumulation of peat that is rich in carbon (C). Thus, typical peat landscapes (raised bogs, blanket bogs and fens) have formed over thousands of years. However, much of this area has been extensively modified by humans (mostly grazed for low-intensity agriculture), and drained to various extents, and currently more than 40% of the peatland area does not have the original hydrophytic vegetation, which has been replaced by forest or grass or removed altogether through peat extraction for energy, horticulture and domestic purposes (Wilson *et al.*, 2013a).

Peatlands are exceptional natural entities. Composed of a unique combination of habitats, they can form a diversity of ecosystems with a unique biodiversity, at species and genetic levels. They represent a considerable national biodiversity resource, with some species being endemic and rare at a global scale. No less than three bog habitats, two fen habitats and six other habitats associated with peatlands are listed in Annex I of the Habitats Directive (EU Directive on the Conservation of Habitats, Flora and Fauna 92/43/EEC) because they are particularly threatened and at risk of disappearance in Europe. At the species level, peatlands are home to flora and fauna of highly significant conservation value, with species new to Ireland still being discovered (Renou-Wilson *et al.*, 2011).

Peatlands are also unique ecosystems because they are generally net sinks for carbon dioxide (CO_2 uptake) and sources of methane (CH_4 emission). Therefore, their climate footprint depends on the magnitude of the land–atmosphere exchange of these two major greenhouse gases (GHGs); nitrous oxide (N_2O) becomes significant only in nutrient-rich fens and when wetlands are converted to agriculture or afforested. Peatlands are large C stores (Limpens *et al.*, 2008; Yu, 2012), and are estimated to contain between 53% and 75% of the total soil organic C stocks in Ireland (Tomlinson, 2005; Renou-Wilson *et al.*, 2011). The accumulation of vast quantities of C occurs over many thousands of years and results from the slow accumulation of partly decomposed plant remains (C-rich organic material) under the water-saturated, oxygen-depleted conditions that prevail in natural peatlands. While the net annual GHG budget of natural peatlands is spatially (Laine *et al.*, 2006) and temporally (McVeigh *et al.*, 2014) variable, it is sensitive to natural and anthropogenic perturbations, and the climate footprint of peatlands has been found to be strongly dependent on their management (Petrescu *et al.*, 2015).

1.1.2 Pressures on peatlands

The current state of Irish peatlands and the consequences of widespread degradation in terms of loss of various ecosystem services have been highlighted by previous research funded by the Environmental Protection Agency (EPA) (e.g. Renou-Wilson *et al.*, 2011; Wilson *et al.*, 2013a), thereby establishing a framework for the development of the first National Peatlands Strategy (2016). Less than 20% of the original peatland area is considered to be worthy of conservation. The most recent state monitoring survey showed that, out of the 310,000 ha of raised bog originally reported by Hammond (1981), 260,000 ha have been affected by peat extraction (industrial and/or domestic turf cutting) (NPWS, 2017). More importantly, out of the remaining “near natural” 50,000 ha of raised bog, only 1955 ha is considered “active” (Fernandez *et al.*, 2014) and capable of C sequestration. Meanwhile, 97% of the country’s fens have been drained (Foss *et al.*, 2001).

The pressures are directly linked to land management, which includes drainage and associated conversion to other land uses, including grassland, cropland (a very small proportion in Ireland) and plantation forestry, or extensive livestock grazing and burning for heather management. Global demand for peat has increased the rates of bog drainage by peat extraction companies (Joosten and Clarke, 2002), while peat still contributes to energy security as an indigenous fuel that is also used for domestic heating in rural parts of Ireland. Overall, it is clear that decisions on land use are often made without knowledge in regard to their climate impacts and represent barriers to the implementation of appropriate mitigation measures (Regina *et al.*, 2015). Studies indicate that global peatland degradation releases approximately 2–3 gigatonnes of CO_2 to the atmosphere annually (Joosten, 2009; Joosten *et al.*, 2012). In Ireland, emissions from Irish peatlands and related activities (combustion of peat for energy, horticulture) are estimated at approximately 3 million t C (~11 million t CO_2) each year (Wilson *et al.*, 2013a). The contribution of peatlands to global and national GHG budgets is still uncertain and represents an "on-going concern" because of limited knowledge in regard to the synergistic response of CO_2 and CH_4 fluxes to (1) environmental variability – local (vegetation, water table, edaphic properties), regional (climate) and ontogenic variation, and (2) management intensity and land use change – rewetting/restoration, drainage for forestry, agriculture or peat extraction. The issue is further exacerbated by climate change making it difficult to devise and implement appropriate restoration activities that will contribute to climate mitigation targets (Renou-Wilson, 2018a).

1.1.3 Solutions: rewetting and restoration

The European Environment Agency has highlighted that more action is needed towards halting biodiversity loss and maintaining the resilience of ecosystems because of their essential role in regulating the global climate system (Zaunberger *et al.*, 2008). Indeed, the biodiversity–climate change nexus is now well recognised and several studies have shown that it is possible to develop strategies that achieve mutually supportive outcomes (Norgaard, 2008; Parish *et al.*, 2008; Royal Society, 2008; Coll *et al.*, 2009). Peatlands, at the heart of the global climate system, are a prime example of where maintaining and enhancing the resilience of the natural ecosystem (including biodiversity) may be the best and most cost-effective defence against climate change. Going one step further on the mitigation ladder, rewetting and restoration of degraded peatlands has been considered a "low-hanging fruit, and among the most cost-effective options for mitigating climate change" [Achim Steiner, Under-Secretary General and Executive Director of the United Nations Environment Programme (UNEP)].

Rewetting and additional restoration measures, together with conservation measures, could provide synergies by reducing GHG emissions and enhancing the biodiversity value of Irish peatlands. However, neither biodiversity nor climate change policies currently fully exploit the potential synergy of the climate change–biodiversity nexus. Our knowledge of rewetted and restored peatlands in Ireland is limited to site- and discipline-specific studies. We need to increase our understanding of the potential of the biodiversity–climate change mitigation nexus as an effective mechanism for sustainable utilisation of our biological resources, while contributing to the development of national policy for the sustainable management of organic soils and climate change mitigation.

1.1.4 Relevance for policy

The potential impacts of human activities on peatlands, combined with other pressures such as climate change, are of interest to a wide range of stakeholders from site managers to international policymakers. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) highlighted the importance of peatlands in climate mitigation measures (IPCC, 2013), while a major European research programme concluded that "the largest emissions of CO_2 from soils result from land use change and especially drainage of organic soils and amount to 20–40 tonnes of CO_2 per hectare per year. The most effective option to manage soil C in order to mitigate climate change is to preserve existing stocks in soils, and especially the large stocks in peat and other soils with a high content of organic matter." (Schils *et al.*, 2008). International biodiversity and climate change conventions, such as the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change (UNFCCC) now recognise peatlands as a priority area for action. At the national level, the Climate Action and Low Carbon Development Bill (2015) identified the establishment of legally binding GHG emissions targets [following European Union (EU) targets] as a key priority in the transition to a low-C economy. This could be achieved through a significant lowering of emissions, especially from managed peatlands.

The need to report on GHG emissions/removals is driven by Ireland's international obligations under the UNFCCC, the European Union Monitoring Mechanism (EUMM), and the Kyoto Protocol. These set out the requirements for international reporting and accounting of emissions from a number of sectors, including land use, land use change and forestry (LULUFC). The IPCC *Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC, 2014*;* hereafter referred to as the *Wetlands Supplement*) has set out methodological guidance for the quantification and accounting of GHG emissions/removals associated with the management of different wetland types and the provision of Tier 1 (i.e. default) GHG emission factors (EFs) for a wide range of drained and rewetted land use categories (LUCs).[1] The primary focus of the *Wetlands Supplement*, and the area of greatest relevance to Ireland, is the drainage and rewetting of organic soils (i.e. managed peatlands).

1.2 Objectives of the NEROS Project

The objective of the NEROS project is to strengthen the knowledge base on the climate change–biodiversity nexus through long-term monitoring and scientific research. This project established a network of both degraded and rewetted/restored peatlands representing all major types of land use management currently pertaining to peatlands and organic soils in Ireland, as well as the foremost ecosystem management options. Biodiversity components and GHG fluxes were monitored and assessed over multi-year periods to evaluate the return of various ecosystem functions, namely the specialised plant biodiversity of peatlands, natural hydrological regime and long-term C sequestration. The ultimate aim was to provide high-quality information to guide policy decisions in recognising the climate change–biodiversity nexus and its benefits in facilitating Ireland's commitment to a more sustainable environment through the reduction of GHG emissions and conservation and sustainable use of a natural resource. The project was divided into three cluster studies: (1) biodiversity studies; (2) GHG studies; and (3) strategies appraisal and policy development studies.

The questions this project aimed to answer were as follows:

1. What are the causes of the degradation of peatlands and future trends?
2. What are the consequences of degraded peatlands and organic soils in terms of impacts on biodiversity and the climate?
3. Can rewetting and restoration of peatlands and organic soils bring back the biogeochemical functions that are vital for the delivery of ecosystem services, which include biodiversity and climate regulation?
4. What sustainable management options can be delivered on priority degraded peatlands?
5. What policy development can be recommended following this investigation and how can it facilitate Ireland's legal requirements under existing international and EU regulations?

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1 Emissions refer to the net movement of GHGs from peatland to the atmosphere and are commonly assigned a positive value. Removals refer to the net movement of GHGs from the atmosphere to peatland and are commonly assigned a negative value.

2 Peatland Land Use in Ireland

2.1 Soil Definitions

In Ireland, organic soils are defined as having high organic matter content (greater than 20%) and a peat depth of greater than 30 cm (see the technical report on http://erc.epa.ie/safer/reports for a detailed definition of peat soils). If the organic or peat layer is less than 30 cm, then the soil is classified as organo-mineral (or peaty-mineral). According to the Irish National Soils Database (Fay *et al*., 2007), the term "organic soils" is used for all soils with a soil organic carbon (SOC) content > 15% (~25% soil organic matter). Wet organic soils are defined as having a water table between 0 and 30 cm below the soil surface. In the *Wetlands Supplement*, wet soils are not defined by the water table but as soils (mineral or organic) that are inundated or saturated by water for all or part of the year to the extent that biota adapted to anaerobic conditions, particularly soil microbes and rooted plants, control net annual GHG emissions/removals (IPCC, 2014).

2.2 Irish Peatland Land Use Categories

Raised bogs, fens, Atlantic blanket bog and mountain blanket bog are typical peatland types found naturally in Ireland. The majority of Irish peatlands have been drained and used for centuries for productive purposes such as agriculture (mostly grazing), forestry and peat extraction (Table 2.1). Certain types of peatlands have been affected by one land use more than others, for example agriculture on fens, forestry on blanket bog and peat extraction on raised bog. Each land use has brought various impacts and disturbance levels to the peatlands, which must be understood before decisions can be made on their future management. Since each peatland is unique in its geographical location, peat composition, hydrology, topography, age, and type and degree of natural disturbances (existing natural pressures), the repercussions of land use change vary from one peatland to the other and create varied "profiles" of degraded peatlands (see the end of project report for detailed description of the impacts of land use on biodiversity and GHG exchange).

2.2.1 Agriculture

An estimated 300,000–375,000 ha of organic soils is under grassland (Wilson *et al*., 2013a) while a mere 1235 ha of organic soils are cultivated (Donlan *et al*., 2016). Agriculture is the oldest land use of peat soils, and reclamation and drainage of organic soils was intensified over the past two centuries as a result of population pressures and several Acts and schemes, including the 1945 Arterial Drainage Act, the Farm Improvement Programme and the Programme for Western Development. Grasslands have also been established over cutaway or cutover peatlands and therefore represent a second land use change. They are typically more fertile, as the nutrient-poor top layer of the bog was removed for fuel and the grassland established in the nutrient-rich "fen" basal layer of the bog. These are mostly confined to the Midlands, where the first raised bogs have been mined and exhausted. They are typically large expanses of flat land and,

Table 2.1. Estimated areas of main peatland land use categories in Ireland

Land use category	Area (ha)	References
Agriculture		
Grassland	300,000–374,690	Wilson *et al*., 2013a; Duffy *et al*., 2015
Arable	1235	Donlan *et al*., 2016
Forestry	321,927	NFI, 2013
Peat extraction		
Industrial	67,715–100,000	Fitzgerald, 2006; NFI, 2013
Domestic	260,000–600,000	Malone and O'Connell, 2009; NFI, 2013; NPWS, 2017
Abandoned	> 20,000	

depending on their location within the catchment, can range from shallow drained (if near a main water body) to deep drained. Although difficult to achieve in a wet climatic condition, well-drained organic soils are among the most productive agricultural lands available. Management of grasslands over organic soils has been described in detail in Renou-Wilson *et al*. (2015).

2.2.2 Forestry

In 2012, 44% or 321,927 ha of the total forest estate was located on peat soils (Table 2.1), with the majority located on blanket bog (234,129 ha) and the remainder (87,798 ha) on raised peat and cutaway peatlands (NFI, 2013). The turn of the 21st century has seen the near end of the afforestation of natural bogs, but the process is on-going on already drained organic soils (cutover and cutaway bogs and some land previously used for agriculture but now being afforested). Specific forest management methods have been developed to account for the different soil conditions and the interactions between terrestrial and water ecosystems. However, Tiernan (2008) has estimated that approximately 20% of peatland forests (64,548 ha) are uneconomic and unsustainable and will require alternative management approaches including bog rewetting/restoration.

2.2.3 Peat extraction

Peat is currently extracted (1) for electricity generation in condensing power plants, (2) for fuel for domestic heating (briquettes and turf), (3) for horticultural products, and (4) as raw material for chemical products, bedding material, and filter and absorbent material. An estimated 75,000–100,000 ha of peatlands are currently utilised for industrial peat extraction in Ireland (Fitzgerald, 2006; NPWS, 2015). However, the total area of peatlands currently affected by domestic peat extraction (mechanical and hand-cutting) remains uncertain and may range between 260,000 and 600,000 ha (Table 2.1). Mechanisation of the process and utilisation of adapted vehicles has allowed for more peat to be extracted over a wider area of bog, in less accessible terrain and also on a semi-commercial basis. This is not an issue confined to raised bogs, as there has been a large rise in the use of the excavator method and hopper method of peat extraction on blanket bogs since the mid-1980s (Conaghan, 2000). However, peat extraction for horticultural products has particularly affected smaller raised bogs that were previously overlooked for industrial peat extraction for energy use. While the after-use of industrial cutaway peatlands is subject to constantly changing land use strategies (dictated mostly by economic factors), it has been predicted that less than 50% of Bord na Móna's land would revert to "wetlands" post rehabilitation, and this includes large areas of open water (Bord na Móna, 2016).

2.2.4 Abandoned drained peatlands and organic soils

The area of drained peatlands and organic soils that has been "abandoned" because of low productivity or the cessation of industrial extraction, or where the practice of turbary has ceased is unclear.[2] In many cases, the former drainage systems continue to function, while in others rewetting may occur naturally. Many peatlands designated as part of the Natura 2000 network contain large degraded areas where sites have not been actively restored. In the absence of proper management, these sites typically retain an oxic layer and are likely to remain a persistent source of CO_2 emissions for decades (Wilson *et al*., 2007a). No data pertaining to this category are currently available.

2 Turbary describes the right to cut turf on a particular area of bog.

3 Rewetting and Restoration of Peatlands and Organic Soils

3.1 Definitions

Ecological restoration is the process of assisting the recovery of a system that has been degraded, damaged or destroyed. Wetland restoration aims to permanently re-establish the pre-disturbance wetland ecosystem, including the hydrological and biogeochemical processes typical of water-saturated soils, as well as the vegetation cover that pre-dated the disturbance (Nelleman and Corcoran, 2010). This definition implies that restoration necessarily includes the process of rewetting in the case of formerly drained areas. However, in some cases, e.g. eroded blanket bog, restoration may necessitate only a change of management (lower numbers of livestock) and may be successful (i.e. restore adequate vegetation cover) without the need for rewetting.

Rewetting is the deliberate action of raising the water table in soils that had previously been drained for forestry, crop production, grazing, peat extraction, etc., to re-establish water-saturated conditions, e.g. by blocking drainage ditches, constructing bunds or disabling pumping facilities (IPCC, 2014). In this context, rewetting has been successful when hydrological and biogeochemical processes characteristic of saturated soils are permanently re-established. However, defining "restoration success" is difficult, as there is no generally accepted definition in an international context. Rewetting/restoration projects and techniques have been developed around the world with various objectives in mind. It is, therefore, critical to state the purpose of the restoration and/or rewetting at the onset of the project so that success in achieving the targets can be clearly demonstrated.

3.2 Purposes of Restoring and Rewetting

Rewetting on its own can have several objectives, such as nature conservation, reductions in GHG emissions or the promotion of other management practices on saturated organic soils, such as paludiculture (IPCC, 2014). These can be achieved by various management schemes and practices, all of which have in common the critical parameter that the mean water level is raised to near to (but not necessarily at) the soil surface. While industrial cutaway peatlands and marginal grassland over organic soil may be the easiest categories of degraded peat soils to successfully re-establish the C sequestration function via rewetting, the rewetting of protected sites that are not in favourable conditions could also be considered additional "low-hanging fruit" mitigation measures to stop C emissions from Irish peatlands. Re-establishing a high water table (Freibauer *et al*., 2004) or optimising the position of the water table (Lloyd, 2006) has been proposed as a successful management measure for mitigating GHG emissions from agricultural organic soils (Smith *et al*., 2007). Recent studies show that it would be possible to determine an optimum water table that would be suitable for grass cultivation (−20 cm) but have lower than expected emissions of N_2O and CO_2, without an accompanying increase in CH_4 emissions (Clay *et al*., 2012; Renou-Wilson *et al*., 2016). However the difficulties of maintaining an optimum water table position following rewetting have been recognised (e.g. Price *et al*., 2003).

There is growing global interest in peatland restoration and in ending non-sustainable uses of peat by bringing back the "sustainable" services and benefits that peatlands provide to society as a whole. Studies in the UK have demonstrated that the long-term benefit of peatland rewetting and restoration on some specific ecosystem services, such as improvement of water storage and quality, has the potential to balance high financial investment (Grand-Clement *et al*., 2013). Positive results have already been demonstrated in Germany, for example, where the full suite of ecosystem services was brought back 10 years after the rewetting of a degraded peatland (Zerbe *et al*., 2013). Large rewetting and restoration projects have already begun around the world (Parish *et al*., 2008; Joosten, 2012). In Belarus, they have successfully demonstrated the reduction of GHG emissions and enhancement of biodiversity values through the restoration and sustainable management of large areas of currently degraded peatlands and, as a consequence, have now developed a scheme for the sale of C credits to secure further peatland rewetting activities and, therefore, future biodiversity protection and enhancement (Tanneberger and Wichtmann, 2011). With other examples in Germany (MoorFutures, http://www.moorfutures.de), and the UK (*The Peatland Code*, Reed *et al*., 2014), new tools (standards and technical guidance) are being developed to enable the corporate sponsorship of the rewetting and restoration of peatlands for climatic benefits, which usually brings additional co-benefits that are not easily monetised (e.g. biodiversity, watershed protection). The continuous development of a rigorous quantification and officially certified recognition system of climatic benefits and co-benefits should help develop regional C markets to fund further peatland restoration and rewetting projects (Bonn *et al*., 2014).

3.3 Rewetting and Restoration Methods

Restoration approaches differ between regions because of factors such as previous land use, peat extraction methods, conditions found on site and lessons learned. Natural peatlands display strong inter-relationships between three main components: the plants, the water and the peat. It is critical to consider all the various peatland components, as seen in Figure 3.1, when assessing the degradation level of each site. The higher the degradation level, the more components are affected and therefore the more difficult the restoration process. It is generally assumed that components that are more difficult to disturb are also more difficult to restore. The different degradation scales have different impacts on each component of the peatlands (Figure 3.1) and therefore will affect the potential for their restoration.

The initial restoration work in Ireland started in the early 1980s on raised bogs that were largely undeveloped and with limited degradation. The research was led by the State Agency [now the National Parks and Wildlife Service (NPWS)], with a team of Dutch and Irish scientists who permitted the development of a detailed hydrological understanding of how hydrological processes support active raised bog habitats. Findings from this research led to the development of damming, drain blocking and lagg management strategies, which were implemented on a handful of protected raised bogs across the Irish Midlands (Schouten, 2002). However, many bogs, including the most researched site, Clara, demonstrate on-going subsidence and degradation due to turf cutting and clearly needed further restorative work (Crushell *et al*., 2008).

Basic restoration techniques, including blocking drains with peat dams and building bunds, have also been used on bogs owned by Bord na Móna. Since 2009, Bord na Móna has restored 1175 ha of raised bog to active (peat-accumulating) raised bog, using drain blocking informed by detailed topographic mapping (Bord na Móna, 2016). Industrial cutaway peatlands present a more challenging environment for restoration work. Therefore, rehabilitation or rewetting (drain blocking and damming) has been implemented in most cases where the deeper fen peat layers are exposed. In this case, fen habitat is the target for restoration. Rewetting in bogs used for

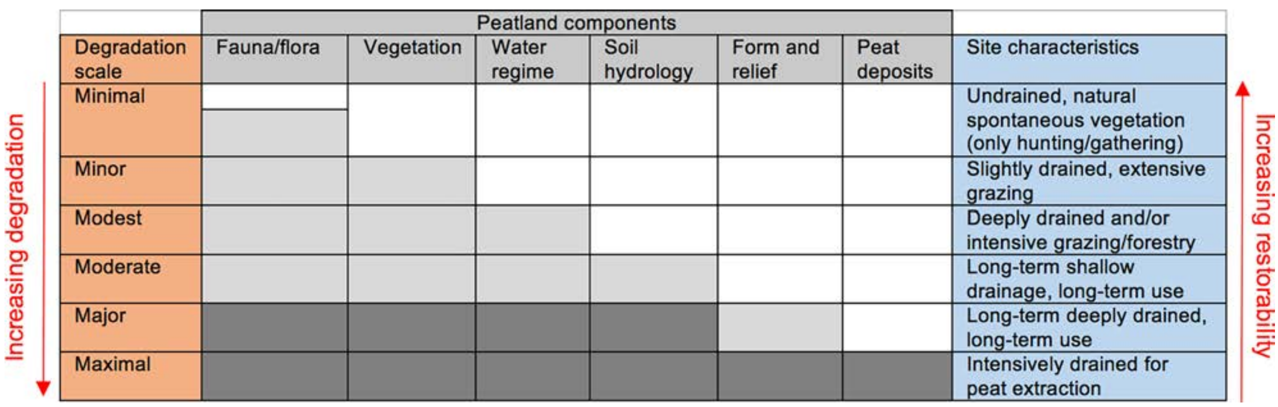


Figure 3.1. Restorability potential according to degradation scale affecting various peatland components. Adapted from Schumann and Joosten, 2008.

horticultural peat is even more problematic because of the significant depth of the drains and the type of peat remaining at the surface, which often coincides with a woody fen peat layer that displays high porosity.

The area of previously afforested bogs that are being restored is increasing, but it remains modest and experimental. With the help of EU funding from the LIFE programme, Coillte have rewetted unplanted and poorly growing conifer plantations. Some 3100 ha of blanket bogs and raised bogs have undergone restoration work so far. Blocking forestry drains (shallower and narrower than Bord na Móna drains) with plastic sheets has been the favoured method, with the use of peat dams at certain sites.

Rewetting of agricultural organic soils has been even more sporadic and on a post hoc basis. Due to rural de-population, ageing farmers and changing labour and input costs, or because sites are remote, commonage land or particularly wet (Strijker, 2005), drainage is not maintained and the land may therefore rewet naturally despite remaining technically “in production” (i.e. cattle or sheep are not fenced off). A detailed description of rewetting/restoration techniques in other countries can be found in the end of project report.

4 Biodiversity Studies

4.1 NEROS Sites

We selected a number of sites across Ireland that represent the range of site types described in Chapter 2, as well as the variation in restoration methods. Included in this network of core sites are those with past or current GHG monitoring, but new sites have also been included that have not been previously investigated. By analysing their habitats and vegetation composition as well as some environmental variables, we aim to draw a picture of these new ecosystems and assess whether or not they are in a trajectory that could be defined as “successful” to return to natural ecosystem.

The 12 biodiversity core sites (Figure 4.1, Table 4.1) are located in the Midlands and the west/north-west of Ireland, where annual precipitation ranges from 845 mm (most easterly sites) to 1245 mm, and annual mean temperature ranges from 9°C to 10°C. The peatland sites were all originally ombrotrophic bogs, either raised bog or blanket bog. However, because of peat extraction, some are now left with an exposed minerotrophic peat layer (basal fen peat). Restored fens, which display very specific individual profiles, were not included in the network.

Four of the core sites also form a long-term GHG monitoring network, which also entails the continuous

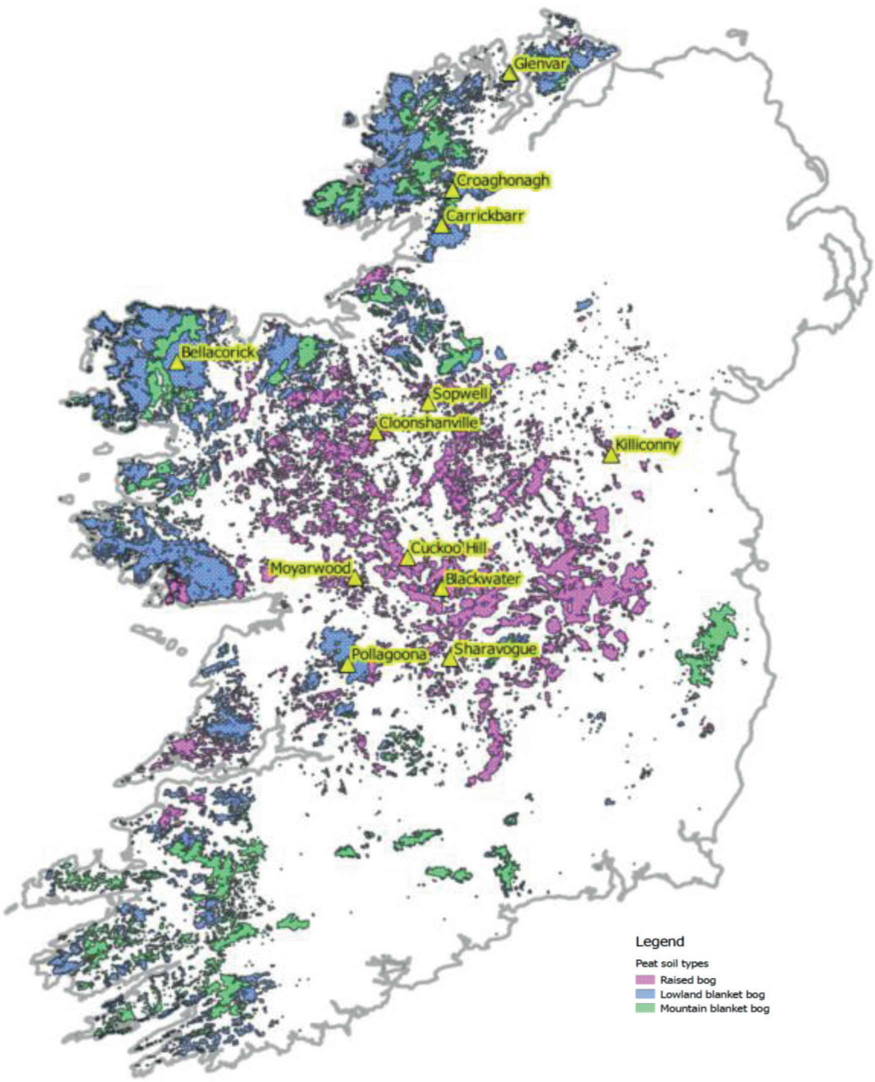


Figure 4.1. Location of the NEROS core biodiversity sites in relation to peat soil types.

Table 4.1. Description of the biodiversity core study sites representing a range of restored/rewetted peatlands and organic soils

Name	Original peatland	Surface peat type	Macro-topography and peat depth	Prior land use	Ecozone and county	Restoration/rewetting method	Year(s) of rewetting
Cuckoo Hill (centre)	RB (pSAC)	*Sphagnum* peat	Flat >4 m	Drained only (BnM) and domestic peat extraction	West Midlands Roscommon	Peat dams	2011
Moyarwood (east)	RB	Cyperaceous peat	Flat >4 m	Drained only (BnM) and domestic peat extraction	West Midlands Galway/Roscommon	Peat dams	2012
Sharavogue (centre)	RB (SAC)	*Sphagnum* peat	Domed > 4 m	Drained only (BnM) and domestic peat extraction	South Midlands Offaly	Peat dams and blocking of drains on lagg zone	1992 and 1997
Killiconny (centre)	RB (SAC)	*Sphagnum* peat	Domed > 4 m	Drained only and domestic peat extraction	North-east Cavan	Plastic dams/profiling face bank/barrier dam on high bog; ponds developed next to face bank	2006–2009
Cloonshanville (east)	RB (SAC)	*Sphagnum* peat	Flat >1 m	Forestry (Coillte)	West Midlands Roscommon	Peat and plastic dams Clear felling to waste	2005
Sopwell/Scohaboy (north)	RB (NHA)	Cyperaceous peat	Flat >2 m	Forestry (Coillte)	South Midlands Offaly	Clear felling and windrowing	2011–2013
Blackwater (centre)	RB	*Phragmites* peat	Flat 50 cm	Industrial peat extraction (BnM)	Midlands Offaly	Cessation of pumping	1999
Croaghonagh (west)	ABB (SAC)	Cyperaceous peat	Gentle slope >1 m	Drained only (unplanted) (Coillte)	North-West Donegal	Plastic dams	2003–2004
Carrickbarr, west of Lough Golagh	HBB (SAC)	Cyperaceous peat	Gentle slope >2 m	Forestry (Coillte)	North-west Donegal	Clear felling to waste and windrowing	2004
Pollagoona (west)	HBB (SAC)	Cyperaceous peat	Gentle slope >2 m	Forestry (Coillte)	Clare	Clear felling to waste and some plastic dams	2006
Bellacorick (centre)	ABB	Cyperaceous peat	Flat >50 cm	Industrial peat extraction (BnM)	North-west Mayo	Peat dams/profiling/bund	2002
Glenvar	OS	"Earthy" peat	Gentle slope >40 cm	Grassland	North-west Donegal	Lack of drainage maintenance	Since 2000

ABB, Atlantic blanket bog; BnM, Bord na Móna; HBB, high blanket bog; NHA, Natural Heritage Area; OS, organic soils; pSAC, proposed Special Area of Conservation; RB, raised bog; SAC, Special Area of Conservation.

monitoring of environmental variables and in-depth vegetation studies. These are Glenvar (rewetted organic soil under grassland), Bellacorick (rewetted cutaway blanket bog), Blackwater (rewetted cutaway raised bog) and Moyarwood (rewetted drained raised bog).

Prior to any fieldwork studies, a desktop study was carried out to gather information on abiotic components (climatic data, geology) and management variables of each of the core sites: land use history, past disturbance (e.g. fires), initial condition, prior restoration work, time since rewetting/restoration (when known), and type of rewetting/restoration measures used, as well as on-going management. In addition, a list of stakeholders, surrounding land uses, and catchment size and location was compiled and/or completed during the first site visit, where visible impacts onsite and from adjacent land use were also recorded as a percentage of the whole site.

The 12 sites belonging to this network were initially grouped into three categories following the degradation scale attributed to each type of disturbance(s) (Table 4.2). For the purpose of comparison, we also used vegetation data recorded from a near-natural raised bog at Clara, County Offaly (Renou-Wilson *et al*., 2011) and a near-natural Atlantic blanket bog at Glencar, County Kerry (Sottocornola *et al*., 2008).

4.2 Methodologies and Analysis

4.2.1 Restored/rewetted peatland assessment survey

The methodologies are described in detail in the end of project report and in the relevant publications from each site. In brief, four key components were identified for the appraisal of the status of a restored/rewetted site: (1) hydrological integrity; (2) physico-chemical parameters; (3) micro-habitat assessment (heterogeneity and condition); and (4) vegetation composition (species and abundance). To carry out an assessment of the first three components, five habitat quadrats (HQs) (4 × 4 m plots) were established along a "W" shaped transect through typical areas at a particular site, running perpendicular to the main drainage systems. In addition, the four corners of each HQ formed a vegetation quadrat or "VQ" (1 × 1 m), and therefore 20 VQs were also identified at each site to assess the fourth component of our survey method. All these parameters were assessed during 2013/2014 at all sites, except at Bellacorick and Glenvar where long-term vegetation surveys have been carried out. The data were recorded into a user-friendly database together with their metadata and appropriate tags to photographic records, thereby creating the first baseline biodiversity database for rewetted/restored peatlands in Ireland. Details of the data analysis can be found in the end of project report.

4.3 Site Survey Results

4.3.1 Physico-chemical parameters

All raised bog sites were overlying limestone, while the base geology of blanket bog sites was more varied, with schist, gneiss, shale and red sandstone. The pH of the raised bog averaged 3.91 (±0.31), with Sharavogue the most acidic. Blackwater has a much more alkaline pH of 5, as its basal fen peat is exposed to the surface. Blanket bogs are more acidic in general [pH = 3.65 (0.15)], with the exception of the grassland site Glenvar, which has a pH of 5.7. Blanket bogs also have the highest carbon to nitrogen (C:N) ratio (i.e. highest C content and poorest N content), with the highest being recorded at Bellacorick (55%). Blanket bogs had an average C:N ratio of 41, compared with a C:N ratio of just under 30 for raised bogs. Sopwell had the highest C content (54%) and Killiconny the lowest (46%).

Table 4.2. Core sites identified according to degradation scale and site disturbance

Degradation scale	Site disturbance	Raised bog sites	Blanket bog sites
Modest	Drained only; low-intensity use	Cuckoo Hill, Moyarwood, Sharavogue, Killiconny	Croaghonagh
Moderate/major	Afforested, reclaimed for agriculture, shallow to deep drainage	Cloonshanville, Sopwell, Glenvar	Pollagoona, Carrickbarr
Maximal	Deeply drained, long-term peat extraction	Blackwater	Bellacorick

4.3.2 Micro-habitat heterogeneity

The relative presence of different micro-habitat types (hummocks, pools, hollows, lawns and flats) provides a measure for habitat heterogeneity for each site (Figure 4.2). Blackwater and Pollagoona were the only sites that completely lacked micro-habitat heterogeneity (i.e. there is only one habitat present on the surveyed part of the site). No significant difference in habitat heterogeneity could be detected between the other sites ($p = 0.06$). Of the original raised bog group, a clear inverse relationship can be seen with the degradation level within the group of original raised bogs. Cuckoo Hill bog displayed the highest relative habitat heterogeneity and is the only site where pools were recorded in three out of the five HQs. Furthermore, all types of pools (regular, interconnecting and tear pattern) were observed at this site and all contained *S. cuspidatum*. Other less degraded sites, such as Moyarwood and Sharavogue, displayed all types of micro-habitats except pools. Restored blanket bogs showed the largest variation in this component, with hummocks being present only in the less degraded (unplanted) site Croaghonagh, while lawns were recorded only at Carrickbarr.

4.3.3 Species richness and diversity

The total number of species (vascular and bryophytes) recorded per site ranged from 18 in Killiconny to 34 in Cloonshanville (Figure 4.3). The proportion of vascular and bryophytes species differed between sites and was not necessarily reflected in the total species number (Table 4.3). The highest proportion of bryophyte species (52%) was observed in Carrickbarr and the lowest in Blackwater (11%). Interestingly, both sites had similar total numbers of species. The drained-only bogs displayed similar total numbers of bryophytes (Table 4.3). However, the highest numbers were found in all previously forested bogs, with higher numbers in the wetter sites. Forested peatlands often include open or undrained areas that provide a seed bank, while the micro-topography can provide for diverse bryophyte assemblages. On the other hand, industrial peat extraction sites, which have lost layers of peat containing such seed banks, or lack neighbouring natural sites, displayed the lowest number of bryophytes; the nutrient-poor site, Bellacorick, had a slightly higher number (five) than the nutrient-rich Blackwater (three) (see end of project report).

The species spread also varied across sites, as shown by the ratio of “species number per plot to total species number”. Blackwater displayed a low ratio (5:27), indicating that some species occur only together. Lower ratios were also found at other degraded sites, including Sopwell and Pollagoona. On the other hand, at low-degradation raised bogs (drained only), 50% or more of all species occurred at all plots. The

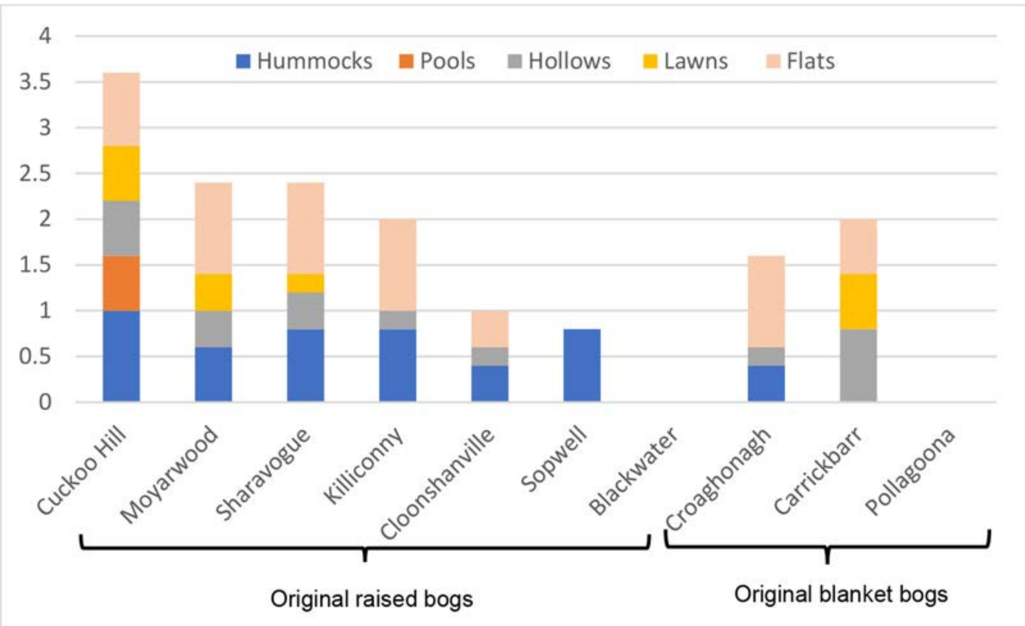


Figure 4.2. Micro-habitat types and relative total heterogeneity found at each study site.

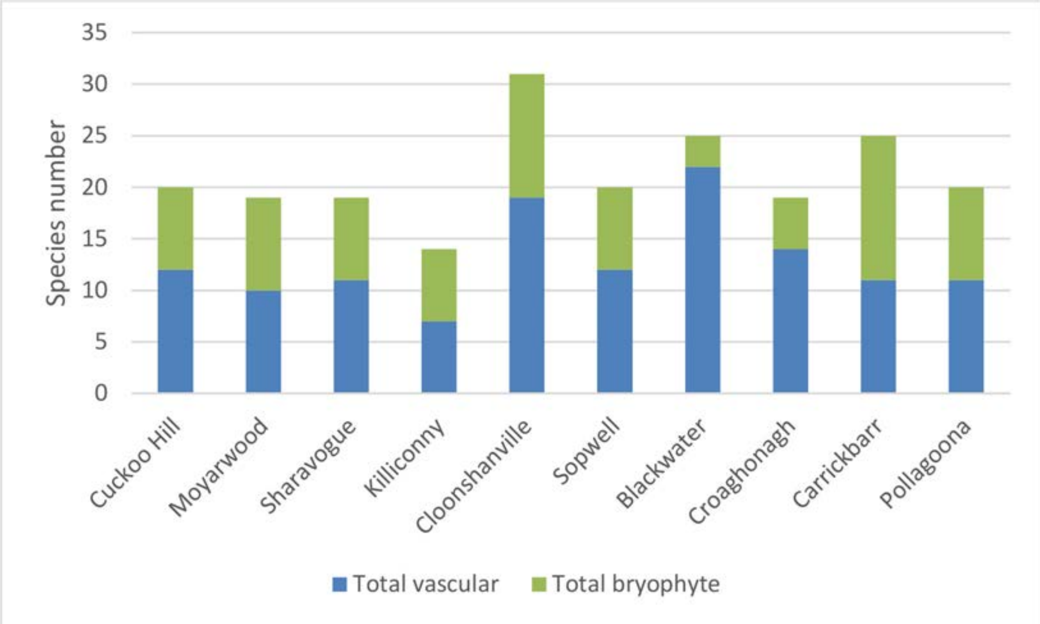


Figure 4.3. Total vascular and bryophyte species number found at each site.

same gradient applies to the Shannon–Wiener Index (SWI), which was highest at Cuckoo Hill (2.27) and Croaghonagh (2.34), while Sopwell and Blackwater had the lowest index (1.29 and 1.34 respectively) (Table 4.3 and end of project report).

4.3.4 Dominant vegetation and Ellenberg indicators

In general, woody species were very rare on all sites and were detected only in very low numbers in Blackwater, Sopwell and Cloonshanville. The same was valid for ferns and algae (appearing at low abundance in Blackwater, Sopwell, Pollagoona and Carrickbarr). The most dominant plant functional types (PFTs) were sedges and *Sphagnum* mosses, followed by ericaceous plants and non-*Sphagnum* mosses (Table 4.3). Grasses were the dominant PFT at all the blanket bogs. Plant litter was detected in high amounts at Blackwater and Sopwell and was also associated with some bare peat. The most abundant single species were *Calluna vulgaris* and *S. capillifolium*, followed by *Eriophorum vaginatum* (on raised bogs) and *Molinia caerulea* (on blanket bogs). Blackwater was noticeably apart from all other bogs in terms of vegetation composition, with *Phragmites australis* and *Carex* sp. the dominant species. Sopwell bog was also distinguished by a high cover of *Rhytidiadelphus squarrosus*, and *Erica tetralix* was the main ericaceous species.

The average Ellenberg indicator values (EIVs) across all sites for moisture (7.5), acidity (2.4) and N (1.9) generally indicated that the sites were damp to wet, quite acidic, and infertile (Table 4.3). The moisture values differed between raised bog sites in the order *cutaway* > *drained only* > *cutover*, but they did not differ between blanket bogs. Blackwater stood apart with the highest moisture, acidity and N values demonstrating that, while being very wet, the peat is more nutrient rich than at the other sites. Sopwell also displayed a higher acidity EIV and nitrogen EIV than the other raised bogs (Table 4.3).

4.3.5 Comparison of vegetation between sites

Calculation of Sørenson’s quotients between each site (Table 4.4) revealed that the Blackwater site had the least similarity with any other sites, ranging between 17% similarity with sites such as Moyarwood and 26% with Cloonshanville. Moyarwood, Sharavogue and Cuckoo Hill all shared 78% similarity in species composition and were also closely similar to Killiconny, Cloonshanville and Sopwell (52–65%). The blanket bogs Pollagoona and Carrickbarr also shared a high similarity of species (65%), but this value decreased

Table 4.3. Biodiversity variables, dominant plant functional types, dominant species and Ellenberg Indicator Values (EIVs) recorded at all sites

Site	Cuckoo Hill	Moyarwood	Sharavogue	Killiconny	Cloonshanville	Sopwell	Blackwater	Croaghonagh	Carrickbarr	Pollagoona
Biodiversity variables										
Total species	21	21	21	18	34	22	27	22	27	22
Bryophyte species	8	9	8	7	12	8	3	5	14	9
Bryophyte/total species ratio	0.38	0.43	0.38	0.39	0.35	0.49	0.11	0.23	0.52	0.41
Shannon–Wiener Index	2.27	2.26	1.39	1.78	2.17	1.29	1.34	2.34	1.9	1.35
Dominant PFTs										
1	S, Sp, M	S	Sp, M	Sp, M	E, Sp, M	L	S	G, S, M	Sp, M, G	G
2	E	Sp, M	S	S, E	M	M	L	E	M	M
Dominant species										
1	Sph. cap.	C. vul.	C. vul.	C. vul.	C. vul.	Rhy. sq.	C. ros.	M. cae.	M. cae.	M. cae.
2	Sph. mag.	Sph. cap.	Sph. cap.	Sph. cap.	E. vag.	Er. tet.	Phr. aus.	Raco. lan.	Sph. cap.	Pol. com.
EIV moisture	7.9	8.0	7.9	7.4	7.5	6.7	8.4	7.0	7.2	7.1
EIV acidity	2.0	2.0	1.9	1.8	2.1	3.0	4.5	2.1	2.2	2.5
EIV nitrogen	1.6	1.5	1.4	1.4	1.7	2.4	3.5	1.5	1.9	2.2

E, ericaceous plants; G, grasses; L, litter; M, non-*Sphagnum* mosses; S, sedges; Sp, *Sphagnum* mosses. Dominant species: *Calluna vulgaris* (C. vul.), *Carex rostrata* (C. ros), *Erica tetralix* (Er. tet), *Eriophorum vaginatum* (E. vag.), *Molinia caerulea* (M. cae.), *Phragmites australis* (Phr. aus), *Polytrichum commune* (Pol. com), *Racomitrium lanuginosum* (Raco. lan), *Rhytidiadelphus squarrosus* (Rhy. sq.), *Sphagnum capillifolium* (Sph. cap), *Sphagnum magellanicum* (Sph. mag).

Table 4.4. Sørenson's quotients between each site. The higher the number (darker colour), the more similar the species list between the sites; the lower the number (lighter colour), the more dissimilar the sites are in terms of species

	Moyarwood	Sharavogue	Killiconny	Cloonshaville	Sopwell	Blackwater	Croaghonagh	Carrickbarr	Pollagoona
Cuckoo Hill	78	71	62	65	60	25	56	58	56
Moyarwood		78	58	63	62	17	57	51	52
Sharavogue			62	65	51	21	51	50	47
Killiconny				46	40	18	40	49	40
Cloonshanville					57	26	43	56	54
Sopwell						20	41	41	45
Blackwater							16	22	20
Croaghonagh								41	36
Carrickbarr									65

to 40% when compared with the other blanket bog at Croaghonagh.

4.3.6 Positive indicators: target species

The presence of *S. capillifolium* at all peatland sites (except Blackwater) is of great significance in rewetted/ restored sites, as it demonstrates the presence of water table levels close to the surface and above. The presence of other *Sphagnum* species such as *S. papillosum* and *S. magellanicum* strongly indicates that vegetation succession is on the correct trajectory. In the case of Blackwater, while the site displays a high water table (even above the ground surface), the high nutrient content of the remaining peat may be the main reason for the absence of *Sphagnum* spp. It is the only site where *Carex* spp. dominated – an indicator of water movement, which may also be nefarious for *Sphagnum* development. *Rhynchospora alba* was present in all sites except Blackwater and the forestry sites. Hummocks are very good indicators of healthy natural bogs and were absent from heavily degraded sites where the peat was extracted or that were forested. *S. capillifolium, S. magellanicum, S. papillosum* and *Hypnum cupressiforme* were dominant components of the hummocks where present. Good indicators of hummock species in natural raised bogs include *S. fuscum* and *S. austinii*, both of which are good peat formers. While the latter was absent from all of our sites, *S. fuscum* was found on one hummock at both Sharavogue and Moyarwood.

Of the list of species typically associated with raised bog ecosystems in Ireland (NPWS, 2013), all but two species of *Sphagnum* (*S. autinii* and *S. denticulatum*) and one bladderwort (*Utricularia minor*) were found across the network of sites. Lichens (mostly *Cladonia portentosa*), a very good indicator of the absence of fire events, were present at all sites except Blackwater.

The presence of *Polytrichum* communes at the restored sites that were previously afforested is an early indicator of increasing moisture content. It is also known as a nurse species, facilitating the colonisation of *Sphagnum* in disturbed peatlands (Groeneveld *et al*., 2007). Pollagoona is the only site where the cover of *P. commune* exceeded 30% in nearly half of the quadrats and has the smallest cover of *Sphagnum* mosses of these site types, reflecting a water table level that is not close enough to the surface to favour *Sphagnum* over *Polytrichum* spp. (Potvin *et al*., 2015).

4.3.7 Negative indicators

Drained-only raised bogs and cutover bogs still included species indicative of drier past conditions, for example an abundant cover of bog asphodel (*Narthecium ossifragum*), deergrass tussocks (*Trichophorum caespitosum*) and hare's-tail cotton-grass tussocks (*Eriophorum vaginatum*). All but Killiconny (located further east) included carnation sedge (*C. panicea*), which is a negative indicator particularly in true "Midlands raised bogs". Of great significance was the absence of common invasive species from all sites except the previously afforested sites, which included a very low cover or absence of woody species such as Scots pine (*Pinus sylvestris*), birch (*Betula pubescens*) and rhododendron (*Rhododendron ponticum*).

4.3.8 Difficulties of a large-scale project: Bellacorick

At Bellacorick, initial re-colonisation was dominated by *Juncus effusus*, which in turn has facilitated the establishment of moss species such as *P. commune* and *S. cuspidatum* (Farrell and Doyle, 2003). In the wettest part of the site, *S. cuspidatum* has flourished at the expense of its nurse species (e.g. *J. effusus*, *E. angustifolium*). The emergence of *Sphagnum*-rich vegetation in the successfully rewetted areas, albeit covering a very small proportion of the site (Fallon, 2013), is a step on the right trajectory. While the areas of open water and bare peat are decreasing annually as a result of rapid re-colonisation, vegetation growth has been sparser on the sloping areas. It is suggested that re-seeding these areas (using geo-textiles or heather brashing), as used in restoration work on UK blanket bogs, could be an option. On the drier edges of the site and along the peat ridges, *P. contorta* (lodgepole pine), *C. vulgaris* (heather) and *R. ponticum* (common rhododendron) are also present and therefore may require long-term management.

Overall these findings suggest that, after 10 years, Bellacorick as a whole has not yet succeeded in developing a diverse and self-sustaining vegetation community akin to an early successional peatland landscape. While this objective may not be achieved across the whole site during a human lifespan, typical blanket bog vegetation communities occurring in small pockets through the site is encouraging. Bellacorick is a unique site in that it is relatively large (6500 ha) and, while it was principally milled for peat extraction, aspects of the site can be compared with afforestation, overgrazing and turf cutting on blanket bog habitats.

4.3.9 Vegetation dynamics of a rewetted grassland over organic soils: impact of grazing

At the Glenvar site (grassland over organic soil), we monitored the vegetation within three areas: (1) a rewetted site where water saturation conditions were re-established; (2) a shallow drained site with the mean annual water table deeper than −30 cm below the soil surface (IPCC, 2014); and (3) a deep drained site where the water table fell typically below −30 cm for most of the year. Over the 4-year monitoring period, the last 2 years were under an “ungrazed” regime.
At the beginning of the study, the rewetted plots had the highest average species number (13.0 ± 1.5), compared with 9.4 ± 1.8 in the drained plots. The lowest species number was in the deep drained area, with 8.4 ± 2.2 (Figure 4.4). The deep drained area contained only 3.3% of wetland species, while this increased to 17% for shallow drained and 19% for rewetted. *Juncus* spp. were present in all rewetted plots but only in two of the shallow drained plots and one of the deep drained plots. At the end of the study period (after 2 years of no grazing), both shallow drained and rewetted sites displayed the same increased average species number of 14.8 (Figure 4.4). This sharp increase in species numbers in the shallow drained site was due to new herb species (*Bellis perennis*, *Taraxacum officinale*) but mainly wetland species (*J. bulbous, J. squarrosus, J. articulatus)*, while shrubs (*Alnus glutinosa* and *Salix* spp.) appeared at both sites. Between year 1 and year 4, the wetland species cover increased dramatically to 30% in the shallow drained plots and 42% in the rewetted plots, and this was predominantly due to rapid growth and spread of *J. effusus*. It is worth noting the appearance of two new moss species at both sites during year 4: *P. commune* and *Fissidens taxifolius*.

4.4 Outcomes from the NEROS Network Sites

4.4.1 Indicators of success or failure

The biodiversity studies carried out as part of this research helped improve our understanding of the ecology of rewetted and restored peatlands and organic soils by combining the relevant information on their hydrological status, physico-chemical characteristics, and micro-habitat and vegetation composition. This investigation demonstrated firstly that all sites have been successfully restored from a hydrological point of view (with water table at or just below surface and high EIV moisture values), except

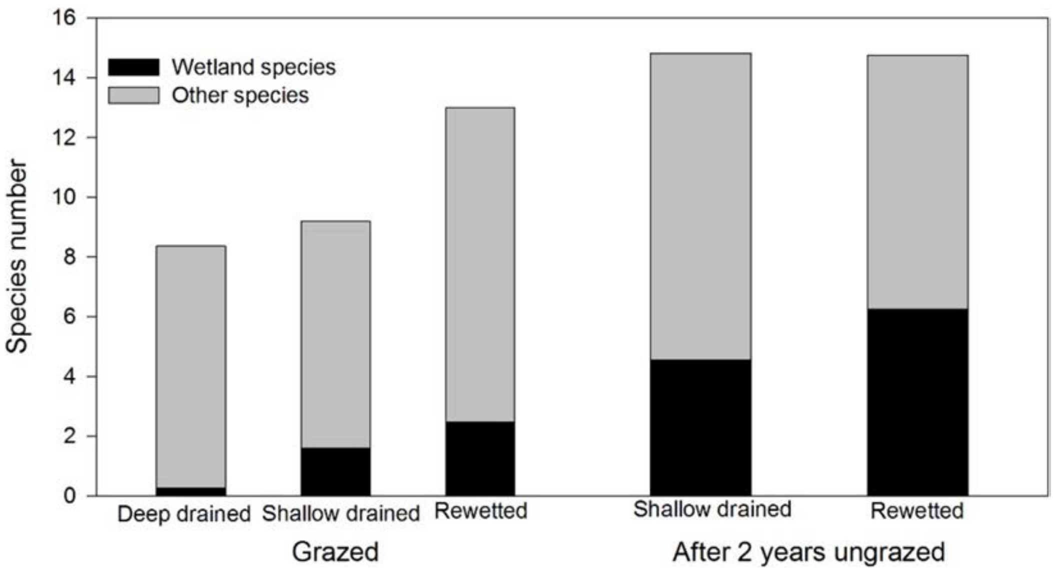


Figure 4.4. Total number of species per plot in deep drained, shallow drained and rewetted sites at Glenvar during the grazed period (year 1) and after 2 years ungrazed (year 4); total bar height represents total number of species, black bars represent number of wetland species and grey bars represent number of other species.

for Sopwell (previously afforested raised bog), which remains a drier site. Species assemblages that form active raised bog, for example, require mean water level to be near or above the surface of the bog lawns for most of the year. In addition, seasonal fluctuations should not exceed 20 cm in amplitude and should be only 10 cm below the surface, and should only be deeper than that for very short periods of time (NPWS, 2017). The acidity is also comparable to natural sites, with Blackwater (cutaway raised bog) having a pH similar to natural fens. Overall, the rewetted sites have successfully returned to harsh wet conditions, similar either to pre-disturbance or to a new ecosystem.

As per their natural counterparts, species diversity was typically found to be low, especially in the less degraded sites. Higher species diversity levels were typically recorded in more degraded sites such as industrial cutaway peatlands (Blackwater) and previously afforested sites (Cloonshanville and Carrickbarr). The latter sites are typical examples of ecosystems in transition where vegetation from previous land use (forestry) co-exists with new raised bog vegetation. As rewetting continues successfully, drier species, especially woody PFTs, should eventually disappear and overall species richness return to that of natural sites. On the other hand, a continued increase in species diversity would signify that "homogenisation" (high number of species common to other neighbouring ecosystems) is at play and implies a failure to restore the site and therefore to recover the biodiversity at site and landscape level (Renou-Wilson *et al*., 2011).

The presence of strongly specialised species (e.g. the carnivorous *Drosera* spp., found on all raised bogs studied except Killiconny, and *Sphagnum* spp.) not only confirms that wet and harsh environmental conditions are prevalent, but increases considerably the conservation value of the sites, as these species do not occur in any other ecosystems on the island.

When comparing our results with typical natural raised bogs and blanket bog data, we can assess the success or failure of each site vis-à-vis the ultimate objectives of rewetting/restoration. The radar graphics (Figure 4.5) display the assessment of mean cover of PFTs for each of the following categories grouped by level of disturbance (see Table 4.2): (1) drained-only raised bog; (2) afforested raised bogs; (3) blanket bogs; and (4) industrial cutaway peatlands. *Sphagnum* mosses, ericoid and sedges formed a typical assemblage of PFTs, which was found on the former drained-only or cutover raised bogs (Figure 4.5a). This grouping demonstrated the closest resemblance to natural raised bog's PFT profile. Non-*Sphagnum* mosses and grasses were typically found together in the rewetted blanket bogs, regardless of their previous land use (Figure 4.5b). The higher cover of grasses, however, is directly linked to previous land use, which would have increased the nutrient status of the site, and these sites with higher grass cover are clearly dissimilar to the profiles of natural blanket bogs. In former afforested raised bog (Figure 4.5c), the cover of the "*Sphagnum* mosses, ericoid and sedges" assemblage was much reduced, with additional PFTs (litter and non-*Sphagnum* mosses), which are usually found in natural raised bogs. In the fourth group, including the two industrial cutaway peatlands, the dominant PFT was "sedges/rushes" with some plant litter, overall forming a divergent pattern when compared with the natural raised and blanket bog sites.

4.4.2 Impact of rewetting on fauna

Several studies have now demonstrated that rewetting and restoring degraded peatlands positively affects faunal diversity. Birds, amphibians, arthropods, and aquatic and terrestrial invertebrates have been positively affected by such management change, mainly as a result of the return of habitat heterogeneity (Tanneberger and Wichtmann, 2011; Görn and Fischer 2015). In Ireland, habitat restoration has also been key to preventing any further loss of bird species and to ensuring that characteristic peatland species are retained (Bracken *et al*., 2008). In Bellacorick, red grouse (*Lagopus lagopus*), a species of conservation interest and a Red-listed bird species of breeding concern in Ireland, has been recorded (Cummins *et al*., 2010). In Scohaboy, curlew (*Nemenius arquata*), a rare breeding bird, and other notable species such as the common lizard (*Zootoca vivipara*), Ireland's only reptile, and the endangered white-clawed crayfish (*Austropotamobius pallipes*) (Conaghan and Derwin, 2016) have been recorded since rewetting in 2011.

Aquatic fauna was also positively affected by rewetting and restoration work, and restored and natural pools have been shown to be similar in their hydrochemistry and in their aquatic micro-invertebrate population

(a)

(b)

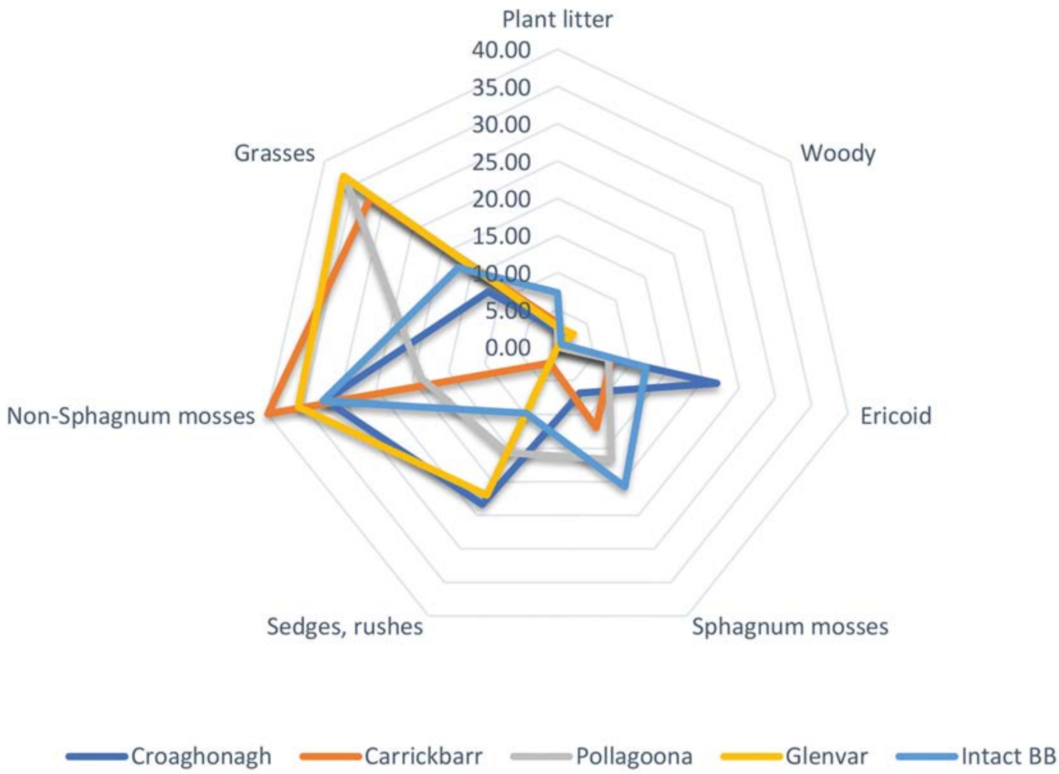
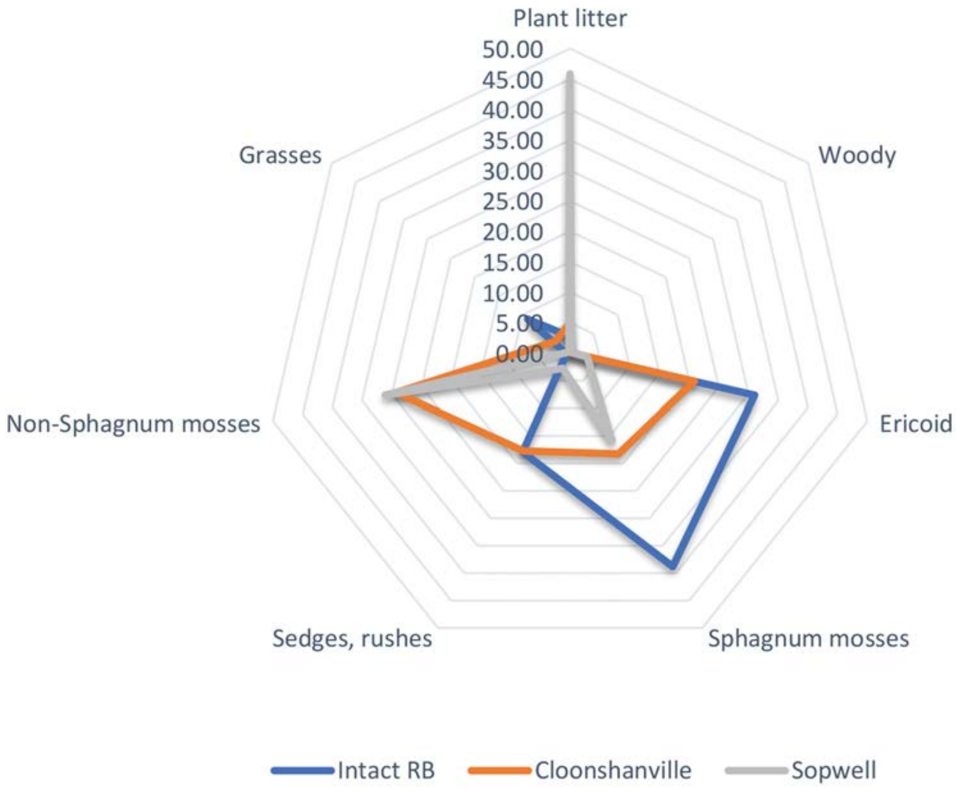


Figure 4.5. Radar graphics displaying plant functional type (PFT) covers by groups of rewetted peatlands and comparison with natural types. (a) Distribution of PFTs in former drained-only raised bogs and natural raised bogs. (b) Distribution of PFTs in former drained/afforested/reclaimed blanket bogs and natural blanket bogs.

(c)



(d)

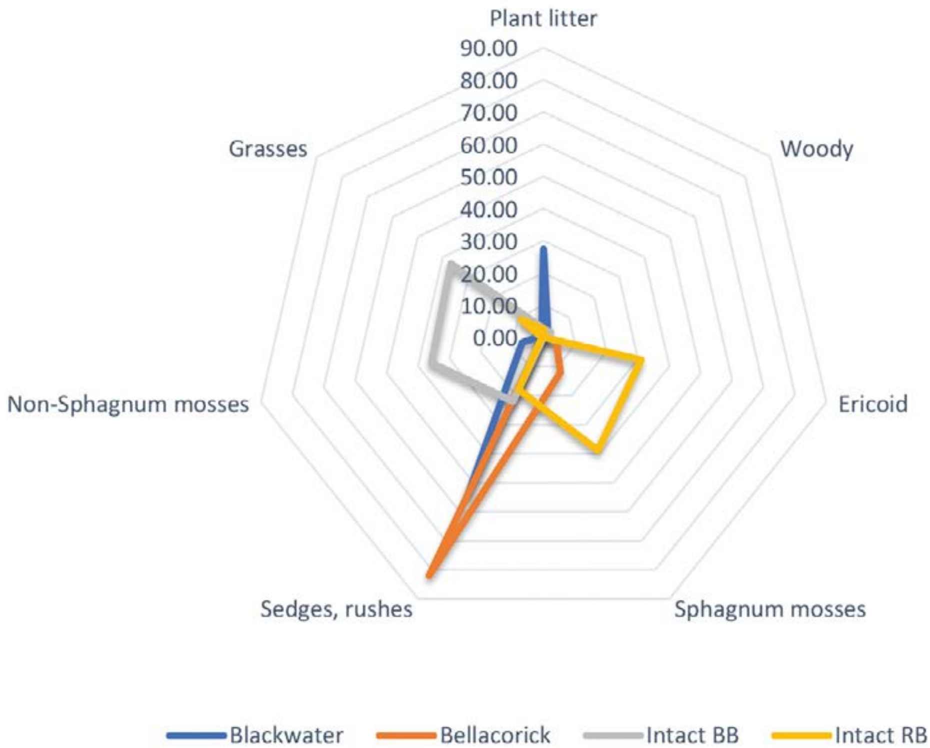


Figure 4.5. Continued. Radar graphics displaying plant functional type (PFT) covers by groups of rewetted peatlands and comparison with natural types. (c) Distribution of PFTs in former afforested raised bogs and natural raised bogs. (d) Distribution of PFTs in former industrial cutaway bogs compared with natural raised and blanket bogs. BB, blanket bog; RB, raised bog.

(Hannigan *et al*., 2011). While it is not certain whether or not the aquatic and terrestrial invertebrate communities can all return to their natural state in all restored peatlands, the return of the heterogeneity of micro-habitats should lead to the establishment of a more diverse spectrum of species, since different species have different requirements (Wieder and Vitt, 2006; Hannigan *et al*., 2011). This is also valid for the microbial communities whose recovery is driven by particular plant groups (Andersen *et al*., 2010). Habitat heterogeneity brought back by rewetting through reduced drainage is also critical to bring back invertebrate populations (Verberk *et al*., 2010). Overall, it is therefore expected that by successfully re-establishing the vegetation succession function in restored/rewetted bog, the overall increased biodiversity value of the site will not be limited to the flora but to al components of biodiversity.

5 Greenhouse Gas Studies

5.1 Study Sites

GHG flux measurements were carried out at six NEROS sites: Bellacorick, Blackwater, Glenvar, Moyarwood, Sopwell and Pollagoona. General details of these sites can be found in Table 4.1 (Chapter 4) and geo-environmental data are provided in Table 5.1. At all but the previously forested sites, we also carried out GHG measurements within a “drained” area of the site that was not rewetted.

5.2 Methodologies

The methodologies pertaining to sampling and data analysis of GHG measurements are described in detail in the end of project report and in the relevant publications from each site. In brief, GHG exchange was measured with the chamber technique (Alm *et al*., 2007). Concurrent to all GHG measurements, soil temperature at depths of 5, 10 and 30 cm, and water table position were measured manually at each measurement collar. Flux rates (mg CO_2/CH_4/N_2O m^{-2} h^{-1}) were calculated as the linear slope of the gas concentration in the chamber headspace over time, with respect to the chamber volume, collar area and air temperature. Vegetation height/cover (cm) was measured regularly and systematically during GHG measurements; see descriptions in Wilson *et al*. (2007b) and Renou-Wilson *et al*. (2014). Fluxes were modelled using non-linear multiple regression

Table 5.1. Site and soil information of NEROS greenhouse gas sites

Site name	Bellacorick	Blackwater	Glenvar	Moyarwood	Sopwell	Pollagoona
Previous land use	Industrial extraction	Industrial extraction	Grassland	Drained/ domestic extraction	Forestry	Forestry
Year of rewetting[a]	2002	1999	2000	2012	2011	2003
Latitude	54.128	53.297	55.159	53.346	52.9741	53.013
Longitude	−9.556	−7.965	−7.575	−8.514	−8.061	−8.544
Sub-region	North-West	Midlands	North-West	West	South Midlands	West
Mean annual air temperature (°C)	10.3	9.8	9.8	10.0	9.3	9.8
Mean rainfall (mm yr^{-1})	1245	907	1076	1193	1173	845
Peat type	Cyperaceous	*Phragmites*	Terric histosol “earthy peat”	*Sphagnum*	Cyperaceous	Cyperaceous
von Post scale	H5 to 6	H7	H9	H6	H7	H7
Parent material	Shale	Limestone	Schist and gneiss	Limestone	Limestone	Old Red Sandstone
Peat depth (m)	0.5	1.5	0.4	4.4	>1.5	0.6
pH	3.8	4.9	4.93	4.4	3.4	3.5
C (%)	56	52.4	23.1	51.5	54.0	53.8
N (%)	0.97	2.14	1.1	1.32	1.6	2.2
C:N	57.7	24.5	21	39	34.2	24.5
Study period	1/1/2009–31/12/2013	1/5/2011–30/4/2015	1/4/2013–31/3/2015	1/4/2013–31/3/2015	1/3/2014–28/2/2015	1/3/2014–28/2/2015
Number of plots						
Drained	6	3	5	3	–	–
Rewetted	12	11	6	12	8	8

[a]At the location of the GHG study. Some parts of the site may have undergone rewetting earlier or later.

techniques and annual GHG balances were calculated for each site.

5.3 Results

5.3.1 *Water table levels*

Water table levels at the six core GHG sites displayed both spatial and temporal variability over the monitoring period extending from January 2011 to April 2015 (Figure 5.1). The drained cutaway site (Blackwater) and drained raised bog (Moyarwood) had the deepest water table levels, extending below −60 cm. Both Glenvar and Bellacorick drained sites are categorised as shallow drained, with the annual mean water table level remaining above −30 cm. All rewetted sites, regardless of microsites, displayed annual mean water table levels above −20 cm and therefore are confirmed as hydrologically restored. The largest amplitude was recorded in the rewetted bare peat sites in Bellacorick and the smallest amplitude in the rewetted microsites composed of *Sphagnum* and *Eriophorum* spp. at the same site (see end of project report).

5.3.2 *Annual GHG exchange*

Bellacorick

The results from the drained and rewetted sites at Bellacorick are described in detail in Wilson *et al*. (2013b, 2015, 2016b) and in the end of project report. In brief, the drained site [dominated by two microsites: bare peat (50% cover) and *J. effusus* (50%)] was a net annual CO_2 source (mean value 0.91 t C ha^{-1} yr^{-1}) and neutral in terms of CH_4 and N_2O exchange (Tables 5.2 and 5.3). In contrast, the rewetted site was a strong CO_2 sink (mean value −1.04 t C ha^{-1} yr^{-1}), although annual CO_2 exchange [net ecosystem exchange NEE)] showed considerable spatial (between microsites) and temporal (between years) variation at the site. NEE was strongly controlled by phenology, light, water table level and soil temperatures. The rewetted site was a net source of CH_4 emissions (92 kg C ha^{-1} yr^{-1}) with considerable spatial and temporal variations observed, driven by differences in vegetation composition, soil temperature and water table level. N_2O emissions/removals were not detected at the site. The CO_2 value is higher

(a)

(b)

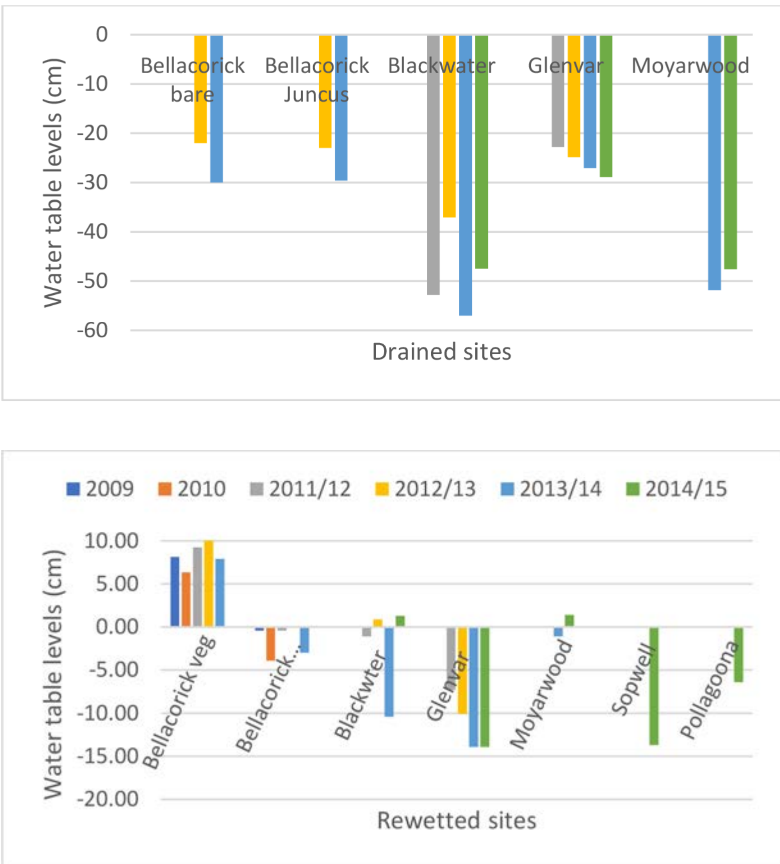


Figure 5.1. Mean annual water table levels (cm) in the (a) drained and (b) rewetted NEROS sites.

Table 5.2. Annual carbon dioxide (CO_2) exchange (NEE) at the drained and rewetted NEROS sites. All units in tonnes C ha^{-1} yr^{-1}. Positive values indicate a net movement of CO_2-C from the peatland to the atmosphere and negative values indicate net removal (uptake) of CO_2-C by the peatland from the atmosphere

Site	Bellacorick		Blackwater		Glenvar		Moyarwood		Sopwell		Pollagoona	
Year	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted
1	–	−1.91	1.62	−1.06	0.87	0.01	1.15	−0.20	–	5.60	–	1.02
2	–	0	1.11	−0.81	0.76	−0.80	1.58	−0.77	–	–	–	–
3	–	−1.71	1.85	1.88	–	–	–	–	–	–	–	–
4	0.71	−1.42	1.45	1.27	–	–	–	–	–	–	–	–
5	1.10	−0.20	–	–	–	–	–	–	–	–	–	–
Mean	0.91	−1.04	1.51	0.32	0.81	−0.40	1.37	−0.49	–	5.60	–	1.02

Table 5.3. Annual methane (CH_4) exchange at the drained and rewetted NEROS sites. All units in kg C ha^{-1} yr^{-1}. Positive values indicate a net movement of CH_4-C from the peatland to the atmosphere and negative values indicate net removal (uptake) of CH_4-C by the peatland from the atmosphere

Site	Bellacorick		Blackwater		Glenvar		Moyarwood		Sopwell		Pollagoona	
Year	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted	Drained	Rewetted
1	–	99	0	169	19	54	–	187	–	26	–	20
2	–	76	0	172	11	34	8	206	–	–	–	–
3	–	69	0	177	–	–	–	–	–	–	–	–
4	0	117	0	172	–	–	–	–	–	–	–	–
5	0	101	–	–	–	–	–	–	–	–	–	–
Mean	0	92	0	173	15	44	8	197	–	26	–	20

(i.e. higher removals) than the Tier 1 EF derived for nutrient-poor rewetted peatlands in the *Wetlands Supplement* (IPCC, 2014) and Wilson *et al*. (2016a), while the CH_4 values are similar.

Blackwater

Annual CO_2 exchange for the first 3 years in the drained site at Blackwater is described in detail in Wilson *et al*. (2015). Here we also report results from a fourth year at the site. Overall, the drained bare peat microsite was a net annual CO_2 source (mean value 1.51 t C ha^{-1} yr^{-1}) (Table 5.2) and was neutral in terms of CH_4 (Table 5.3) and N_2O exchange. The rewetted site is covered by reeds (33%), sedges (33%) and open water (33%). Over the study period, the reeds were a net CO_2 sink of −0.37 t C ha^{-1} yr^{-1} and the sedges were a net CO_2 source of 0.91 t C ha^{-1} yr^{-1}. Inter-annual variation in NEE was very high, driven by considerable differences in annual precipitation and the subsequent position of the water level (see Renou-Wilson *et al*., 2018b and end of project report). CH_4 emissions were highest in the reeds (78 kg C ha^{-1} yr^{-1}) and lowest in the sedges (43 kg C ha^{-1} yr^{-1}). N_2O emissions/removals were not detected at the site. When upscaled,[3] the rewetted site was a source of 0.32 t CO_2-C ha^{-1} yr^{-1} and 173 kg CH_4-C ha^{-1} yr^{-1}. These values are in close agreement with the Tier 1 EF derived for nutrient-rich rewetted peatlands in the *Wetlands Supplement* (IPCC, 2014) and Wilson *et al*. (2016a).

Glenvar

Annual GHG exchange over a 4-year period in the drained and rewetted sites at Glenvar is described in detail in Renou-Wilson *et al*. (2015, 2016). In this synthesis report, we report only GHG exchange for the ungrazed period of the study (i.e. years 3 and 4). During that time, the drained site was a CO_2 source of 0.81 t C ha^{-1} yr^{-1}, considerably lower than emissions reported for other drained organic soils in the temperate zone (Renou-Wilson *et al*., 2016 and references therein). The drained site also emitted 15 kg CH_4-C ha^{-1} yr^{-1}, which is lower than the *Wetlands Supplement* default emission factor (29.2 kg CH_4-C ha^{-1} yr^{-1}) for shallow-drained nutrient-rich organic soils (Table 5.4). The rewetted site was a small net CO_2 sink of −0.4 t C ha^{-1} yr^{-1} (Table 5.2), and a CH_4 source of 44 kg C ha^{-1} yr^{-1} (Table 5.3). This fits well with other rewetted study sites (Beetz et al., 2013; Herbst et al., 2013) and supports the hypothesis that such sites should behave similarly to natural organic soils (Sottocornola and Kiely, 2005; IPCC, 2014).

Moyarwood

The drained site was a CO_2 source of 1.15 and 1.58 t C ha^{-1} yr^{-1} in the first and second year respectively (Table 5.2), caused by high respiratory losses (plant and soil derived) controlled by soil temperature and low soil moisture content (Renou-Wilson *et al*., 2018). The rewetted site was a CO_2 sink for 3 months (March–May) during the first year of monitoring (the site had been rewetted the previous year) but remained a very small CO_2 source for the rest of the time, while in the second year the site was a CO_2 sink for 9 months of the year (see Renou-Wilson *et al*., 2018b and end of project report). Overall, the rewetted site was a small sink for CO_2, with a 2-year mean NEE value of −0.49 t C ha^{-1} yr^{-1}. CH_4 emissions at the drained site were low (~8 kg C ha^{-1} yr^{-1}) and close to the default emission factor reported in the *Wetlands Supplement* for drained peat extraction sites (IPCC, 2014). CH_4 emissions at the rewetted site were much higher than the drained site [187–206 (2-year mean 197) kg CH_4-C ha^{-1} yr^{-1}] but were within the range reported for rewetted nutrient-poor sites in the *Wetlands Supplement* (Table 5.4).

Sopwell

The rewetted site is composed of three main microsites: brash (46% cover), *Sphagnum*/sedges (19%) and lichens/non-*Sphagnum* mosses (35%). All microsites were net CO_2 sources; the brash microsite displayed the highest annual CO_2 emissions (8.19 t C ha^{-1} yr^{-1}), followed by *Sphagnum*/sedges (6.12 t C ha^{-1} yr^{-1}) and lichens/non-*Sphagnum* mosses (1.94 t C ha^{-1} yr^{-1}). CH_4 emissions varied temporally and spatially and followed the sequence: brash > lichens/non-*Sphagnum* mosses > *Sphagnum*/sedges.

3 GHG exchange from open water was not quantified in this study, so for purposes of upscaling, values of 0.43 t CO_2-C ha^{-1} yr^{-1} and 397 kg CH_4-C ha^{-1} yr^{-1} from a comparable nutrient-rich rewetted site were used (Franz *et al*., 2016).

Table 5.4. Tier 1 carbon dioxide (CO_2; $t\,CO_2$-C $ha^{-1}\,yr^{-1}$) and methane (CH_4; kg CH_4-C $ha^{-1}\,yr^{-1}$) emission factors and uncertainty range for the land use categories (IPCC, 2014) studied at the NEROS sites. Mean values from this study are presented for comparison purposes

Land use category	Carbon dioxide		Methane[a]	
	IPCC (2014) Tier 1	This study	IPCC (2014) Tier 1	This study
Grassland shallow drained[b]	3.6 (1.8 to 5.4)	0.81 (0.76 to 0.87)	29 (−2 to 61)	15 (11 to 19)
Grassland nutrient-poor rewetted	−0.23 (−0.64 to 0.18)	−0.40 (−0.80 to 0.08)	92 (3 to 445)	44 (34 to 54)
Peat extraction drained	2.8 (1.1 to 4.2)	1.26[c] (0.91 to 1.51)	4.6 (1.2 to 8.25)	2.7[c] (0 to 8)
Peat extraction nutrient-poor rewetted	−0.23 (−0.64 to 0.18)	−0.77[d] (−0.49 to −1.04)	92 (3 to 445)	145[d] (92 to 197)
Peat extraction nutrient-rich rewetted	0.5 (−0.71 to 1.71)	0.32 (−0.80 to 1.88)	216 (0 to 856)	173 (169 to 177)
Forest land drained	2.6 (2 to 3.3)	nd	1.9 (−0.5 to 4.3)	nd
Forest land nutrient-poor rewetted	−0.23 (−0.64 to 0.18)	3.31[e] (1.02 to 5.60)	92 (3 to 445)	23[e] (20 to 26)

[a]**Units in Chapter 2 (drained organic soils) IPCC (2014) are given as kg CH_4 $ha^{-1}\,yr^{-1}$ and in Chapter 3 (rewetted organic soils) IPCC (2014) as CH_4-C $ha^{-1}\,yr^{-1}$. We use the latter here and have adjusted the Tier 1 values for drained sites accordingly.**

[b]**Values presented for Tier 1 are for shallow drained, nutrient-rich grassland.**

[c]**Mean value from Bellacorick, Blackwater and Moyarwood.**

[d]**Mean value from Bellacorick and Moyarwood.**

[e]**Mean value from Sopwell and Pollagoona.**

nd, no data.

Measured N_2O fluxes over the study period were small and peaked in July during a period when the water table across the study area dropped below 10 cm, but they were either non-existent or below detection for the remainder of the year. Highest N_2O emissions were observed in the lichens/non-*Sphagnum* mosses microsite, which also had the deepest annual mean water table.

When upscaled,[4] the rewetted site was a source of 5.6 t CO_2-C $ha^{-1}\,yr^{-1}$, well above the range reported for all rewetted sites by the *Wetlands Supplement* (IPCC, 2014) and Wilson *et al*. (2016a). In contrast, the upscaled emissions of 26 kg CH_4-C $ha^{-1}\,yr^{-1}$ (Table 5.3) are at the lower end of the range reported (Table 5.4). Upscaled N_2O emissions were estimated at 0.31 kg N_2O $ha^{-1}\,yr^{-1}$, substantially above those reported by Wilson *et al*. (2016a) for rewetted sites.

Pollagoona

The rewetted site (Rigney *et al*., forthcoming) is dominated by three microsites: *M. caerulea* (37% cover), *Sphagnum*/sedges (32%) and *C. vulgaris* (7%). The *Calluna* microsite was as an annual CO_2 sink (−1.43 t C $ha^{-1}\,yr^{-1}$) despite displaying the deepest mean annual water table of all microsites (i.e. −18 cm). However, the water table remained above −30 cm in the summer months, unlike the *Molinia* and *Sphagnum*/sedges microsites, which reached depths below −40 cm in the summer months and emitted 1.68 and 1.85 t CO_2-C $ha^{-1}\,yr^{-1}$ respectively. All microsites were an annual source of CH_4 and followed the sequence: *Calluna* < *Sphagnum*/sedges < *Molinia*, with emissions from the last five times higher than from *Calluna*. Measured N_2O fluxes over the study period were small but variable with positive, negative and zero values recorded.

4 Upscaled annual GHG exchange calculated using the Biodiversity Data Survey of this project.

When upscaled,[5] the rewetted site was a source of 1.02 t CO_2-C ha^{-1} yr^{-1}, within the range for nutrient-rich rewetted sites reported by the *Wetlands Supplement* (IPCC, 2014) and Wilson *et al*. (2016a). In contrast, the upscaled emissions of 20 kg CH_4-C ha^{-1} yr^{-1} (Table 5.3) are at the lower end of the range reported. Upscaled N_2O emissions were estimated at 0.33 kg N_2O ha^{-1} yr^{-1}, substantially above those reported by Wilson *et al*. (2016a) for rewetted sites.

5.4 Climate Change Mitigation

Peatland ecosystems influence climate regulation in two fundamental ways. Firstly, natural peatlands sequester and store vast quantities[6] of CO_2 and also release significant amounts of CH_4, although over millennia this has a net cooling effect on the global climate (Frolking and Roulet, 2007). Secondly, drained peatlands are significant sources of GHG emissions (mainly CO_2 and N_2O) to the atmosphere (IPCC, 2014) with the leading causes identified as unsustainable land management and land use change (Parish et al., 2008; Renou-Wilson et al., 2011). In this study, rewetting resulted in a considerable reduction in net CO_2 emissions and an increase in CH_4 emissions (Tables 5.2 and 5.3) compared with drained sites, which is in agreement with the findings of Wilson *et al*. (2016a) for a large GHG dataset that covered boreal, temperate and tropical peatland sites. Rewetting creates a highly anaerobic environment where oxygen diffusion rates are estimated to be 10,000 times slower than in aerobic conditions (Armstrong, 1980). As a consequence, CO_2 emissions following rewetting can be reduced by 50% even in the absence of vegetation (Wilson et al., 2016b). While CH_4 emissions from the drained sites in this study were generally low (e.g. Renou-Wilson *et al*., 2014, 2016b), research has shown that drainage ditches (not quantified in this study) can remain significant CH_4 emission "hotspots" (Minkkinen and Laine, 2006; Evans *et al*., 2016) and thereby make an important contribution to the overall GHG balance of drained sites (Wilson *et al*., 2016a). Furthermore, losses of dissolved organic carbon (DOC) from drained sites [quantified only at the Glenvar site in this study (Barry *et al*., 2016)] are generally much higher than observed at undrained peatlands but are considerably reduced following rewetting (Evans *et al*., 2016).

There was a wide difference in the magnitude of annual GHG emissions/removals across the rewetted NEROS sites and this reflects the intrinsic variation in site characteristics, namely previous land use and current vegetation composition. Even *within* sites, strong inter-annual variation in GHG dynamics was evident in the multi-year datasets, driven primarily by annual differences in weather (precipitation, light), and the subsequent changes in water table levels and soil temperatures. At three of the rewetted sites (Bellacorick, Glenvar and Moyarwood) the C sink function was restored, as CO_2 removals were higher than CH_4 emissions. In contrast, three sites (Blackwater, Sopwell and Pollagoona) were a source of both CO_2 and CH_4. In addition, Sopwell and Pollagoona, the two previously afforested sites, were small N_2O sources.

5 Upscaled annual GHG exchange calculated using the Biodiversity Data Survey of this project. As GHG emissions/removals were not quantified in around 28% of the site covered by *J. effusus* with a sub-layer of either *Sphagnum* or non-*Sphagnum* mosses in the wetter plots, emission factor values from a comparable microsite in the Glenvar site were used.

6 Globally, more C is stored in soils (2.5 billion tonnes) than in the atmosphere (800 million tonnes) and above-ground plants (560 million tonnes) combined.

6 Rewetting Peatlands for Climate and Biodiversity Benefits: A Balancing Act

6.1 Functional Links Between Biodiversity and Ecosystem Services

Restoration of degraded ecosystems has been recognised as a critical measure for reaching global biodiversity targets and for the maintenance of ecosystem services that can support local human communities while at the same time maintaining and conserving C-rich ecosystems such as peatlands (Millennium Ecosystem Assessment, 2005). Several studies have already highlighted the links between biodiversity and the provision of ecosystem services and provide a strong rationale for the restoration of degraded peatlands. For example, the restoration of peatlands has been shown to have beneficial consequences for human wellbeing (Parry *et al*., 2014; Bonn *et al*., 2016) with improvements observed in water quality (Martin-Ortega *et al*., 2014), climate mitigation (Joosten *et al*., 2016) and biodiversity at all levels (Ramchunder *et al*., 2012; Parry *et al*., 2014). Vegetation composition can directly and indirectly affect critical ecosystem services through its influence on ecosystem processes (e.g. biomass production and C sequestration, nutrient and water cycling, habitats for rare or threatened fauna). Of particular significance in rewetted/restored peatland sites is the ability of certain vegetation assemblages to sequester C. Since certain vegetation assemblages are better at sequestration than others (Belyea, 1996; Dunn *et al*., 2016), plant community structure in rewetted sites could be altered in order to maximise C uptake and storage. Such an ecosystem service could be prioritised in the future as a mitigation measure against climate change (Ward *et al*., 2013).

6.2 Is There a Trade-off Between Climate Regulation and Biodiversity Provision?

The outcome of the rewetting/restoration activities are very much site specific, which makes valuation of ecosystem services provided by these sites a challenge (Glenk *et al*., 2014). Nevertheless, a robust valuation is needed if current land use management and alternative uses are to be compared for local, regional or national policy development, where it is critical to simplify the links between functional processes, such as the condition of vegetation (composition and cover) and habitats, and the related ecosystem services.

In this study, we assessed biodiversity at the site level with three metrics: micro-habitat diversity, the number of bryophyte species present and the SWI. By assigning a ranking to each metric based on our analyses of each site (Table 6.1), our results indicate that rewetting of Moyarwood (a drained-only raised bog) produced the best outcome for biodiversity, with little difference in outcomes between the other five sites. This should not be altogether surprising given that Moyarwood has been subject to *modest* degradation and site disturbance in comparison with the moderate/major or maximal degradation experienced by the other sites (Table 4.2), and in this regard it is potentially similar to many of the degraded “domestic extracted” sites around the country. Vegetation species most characteristic of intact raised bogs are present to some degree on this site and the rewetting actions (drain blocking) have been highly successful in raising the water table to close to or above the soil surface, and crucially maintaining it at high levels over time, which is critical not only for peatland biodiversity but also for climate benefits.

On the basis of the decision matrix analysis (Table 6.1), the rewetted industrial cutaway site at Bellacorick and the rewetted grassland at Glenvar would provide the best benefits for climate regulation (in relation to GHG emissions from drained counterparts), followed by Moyarwood, Blackwater and Sopwell/Pollagoona. However, given the high global warming potential values associated with CH_4 and N_2O (Myhre *et al*., 2013), it is likely that all the rewetted sites have a warming impact on the global climate but at a level lower than drained sites (cf. Renou-Wilson *et al*., 2016; Wilson *et al*., 2016a, 2016b). Three of the sites (Bellacorick, Blackwater and Glenvar) scored higher for climate mitigation than for biodiversity provision,

Table 6.1. Decision matrix for ecosystem services, climate regulation and biodiversity provision in the six NEROS sites. Rankings (1 = very poor; 2 = poor; 3 = moderate; 4 = good; 5 = very good) are assigned to each study site based on the results presented in Chapters 4 and 5

	Climate change mitigation				Biodiversity				
Site	CO_2	CH_4	N_2O	Total	Micro-habitat diversity	Bryophytes species	Shannon–Wiener Index	Total	**Overall total**
Bellacorick	5	3	5	13	2	3	2	7	**20**
Blackwater	3	2	5	10	2	2	2	6	**16**
Glenvar	4	4	5	13	1	2	2	5	**18**
Moyarwood	4	2	5	11	5	5	3	13	**24**
Sopwell	1	4	3	8	2	4	2	8	**16**
Pollagoona	1	4	3	8	1	5	2	8	**16**

two (Sopwell and Pollagoona) were similar and Moyarwood scored higher for biodiversity. When the results from biodiversity and climate mitigation were combined in the decision matrix (Table 6.1), rewetting of Moyarwood produced the highest score followed by Bellacorick, Glenvar and Blackwater/Sopwell/Pollagoona. An in-depth analysis of the two degraded raised bogs Moyarwood (cutover, drained) and Blackwater (industrial cutaway) demonstrated that the re-introduction of broyphytes typical of natural raised bogs may be more difficult than the achievement of proper GHG emission savings (Renou-Wilson *et al.*, 2018b).

6.3 What Sustainable Management Options Can Be Delivered on Priority Degraded Peatlands?

The overall economic perspective of a transition from drained land use to rewetted land use of industrial peatlands has yet to be fully appraised. Certainly, the cost-effectiveness of restoration/rewetting activities in providing the desired outcomes in terms of ecosystem services must also be considered (Adame *et al.*, 2015). Rewetting costs will be highest at the start of the process regardless of the previous land use, although the rewetting actions themselves are highly site specific, e.g. drain blockage, creation of shallow pools and bunds, etc. As such, the costs associated with rewetting may vary considerably between land use categories.

In recent years, a number of sustainable rewetting land use options have been investigated that potentially can encompass biodiversity provision and climate change mitigation. Paludiculture as a land use has been shown to have a positive effect on climate and environment, produce renewable resources without competing with food production, and contribute to the development of rural areas (University of Greifswald, 2012). It centres on the harvesting of biomass (e.g. reeds, grasses, trees, mosses) from wet peatlands, which can be used in variety of ways (e.g. co-firing for energy generation, peat compost substitution, wood products). In particular, *Sphagnum* farming is one example of "wet farming" that has received much attention, and research has made substantial progress with experimental sites established in Canada (Pouliot *et al*., 2014) and Germany (Gaudig *et al*., 2014) whereby *Sphagnum* moss production and a return of biodiversity were both achieved (Muster *et al*., 2015). More information about Irish trials can be found in the technical report. While *Sphagnum* farming can potentially yield a "green product", the action of rewetting degraded peatlands for biomass production could also bring additional benefits in terms of reductions in CO_2 emissions, water storage/flood control, water purification and erosion control. These additional ecosystem services are increasingly becoming economic commodities (Bonn *et al*., 2014).

6.4 Policy Developments to Facilitate Existing International and EU Regulations

Wetland drainage and rewetting (WDR) is an elective activity that parties may choose to report for the second Commitment Period (CP2) of the Kyoto Protocol, but it is not currently a mandatory reporting requirement under any international agreement. It applies to all lands that have been drained and to all lands that have been rewetted since 1990, and countries that elect to report under this activity are also able to claim C benefits from the rewetting of drained peatlands. Lacking critical areal data on wetlands and on peatlands specifically, Ireland has decided not to elect to report on WDR activity for CP2. However, WDR is potentially a very significant development on several accounts. First, it should provide an impetus for the rewetting of high-emitting LUCs, such as peatlands managed for extraction and nutrient-rich organic soils under grassland, both of which represent significant areas (Table 2.1) and are currently persistent long-term hotspots of C emissions. Second, Ireland (like the UK) is unusual in having large areas of peatlands that were historically drained but not converted to intensive agriculture and which may have retained a semi-natural vegetation cover. Opting for a future sustainable land use of these priority areas could contribute to the reduction of GHG emissions, facilitating Ireland's legal requirement under climate change conventions and many EU directives, notably the Habitats Directive, the Birds Directive, the Water Framework Directive and the Landscape Directive, as well as being able to deliver on the sustainable management of one of its last natural resources as envisaged in its National Peatlands Strategy.

There is currently no decision framework for the selection of priority areas for management/restoration. The decision-making process currently relies on data already acquired with no engagement with the stakeholder community. Despite interest from stakeholders (e.g. non-governmental organisations pooling resources to buy and restore degraded peatlands; Bord na Móna's drained-only sites have been put forward to be included in the network of designated raised bogs), a transparent process to select the best sites for rewetting is not in place.

Responding to concerns from the European Commission in regard to the conservation and management of Ireland's designated raised bog Special Area of Conservation (SAC) network, the National Raised Bog Management Plan (NPWS, 2017) is the first major step towards such a framework. It provides information on how the designated network of raised bog SACs and Natural Heritage Areas (NHAs) will be managed, conserved and restored in co-operation with landowners and local communities. The plan sets national restoration targets for raised bog habitats that require the restoration of the national network of raised bog SACs and NHAs. However, this plan affects only designated raised bogs, which represent 5–10% of the original raised bog resource (i.e. 15,000–30,000 ha) and less than 2% of the total national peatland area.

High-resolution maps of Irish peatlands under various management/land uses and disturbance regimes and of varying restoration potential do not currently exist. A national strategy for rewetting peatlands and organic soils should be established to select the best sites to maximise a reduction in C losses and potential for C sequestration and to increase biodiversity benefits. This should be aided first by the creation of a map of disturbances and land use of organic soils. Then stakeholder meetings should be held to present information about the site: biological and physical attributes, management regime, conservation objectives if present, availability of funding, etc. The targets of restoration should be widened so that all benefits arising from the return of ecosystem functions can be acknowledged and some of them quantified in economic terms. This will help in the selection of cost-effective areas to be restored.

Monitoring is a key element of restoration and assessing its success. Despite recent management interventions at various sites around the country, the ecological consequences of blocking drainage ditches on all biodiversity levels (e.g. aquatic fauna on and off site) are poorly understood, for example when the restoration of a peatland may affect adjacent freshwater rivers inhabited by key species such as the freshwater pearl mussel (*Margaritifera margaritifera*). Biodiversity data have been gathered in some specific sites but this needs to be integrated into a national restoration baseline dataset and long-term evaluations suitably funded. Meanwhile, assessing GHG emissions and removals is also necessary but does require more extensive, time-consuming and expensive monitoring programmes. However, work elsewhere has shown that GHG proxy measurements, such as the use of vegetation communities, can be used to provide estimates of GHG emissions/removals from peatland sites (e.g. Couwenberg *et al*., 2011; Gray *et al*., 2013).

7 Final Observations and Recommendations

7.1 Recommended Priority Peatland Land Use Categories for Rewetting

We recommend that the degraded peatland LUCs monitored in this study should be prioritised in terms of rewetting *in the following order* to maximise biodiversity provision and climate change mitigation and taking full cognisance of the potential areas of each LUC.

1. Rewetting drained-only and domestic cutover areas

- *Benefits*: high biodiversity provision, high CO_2 emissions avoided, high areal coverage (Table 2.1).
- *Disadvantages*: moderately high CH_4 emissions, potential costs involved in rewetting, difficulty in maintaining a high water table in some sites.

2. Rewetting grassland areas

- *Benefits*: modest biodiversity provision, high CO_2 emissions avoided, paludiculture options, high areal coverage (Table 2.1).
- *Disadvantages*: moderate CH_4 emissions, potential costs involved in rewetting, difficulty in maintaining a high water table in some sites.

3. Rewetting industrial cutaway areas

- *Benefits*: high CO_2 emissions avoided, paludiculture options, medium areal coverage (Table 2.1).
- *Disadvantages*: low biodiversity provision (but potentially new ecosystem diversity), moderate CH_4 emissions, difficulty in maintaining a high water table in some sites.

4. Rewetting afforested areas

- *Benefits*: modest biodiversity provision, medium areal coverage.
- *Disadvantages*: high CO_2 emissions, priming effects from brash decomposition, moderate CH_4 emissions, potential N_2O emissions, difficulty in maintaining a high water table in some sites.

7.2 Summary of Observations and Associated Recommendations

- **Observation 1**: Long-term monitoring of GHG emissions from the NEROS network sites demonstrated that drained peat soils are significant hotspots of CO_2 emissions that are strongly controlled by soil temperature, water table level and vegetation composition. These data also expand our national GHG dataset and contribute to the reporting of GHG emissions from managed peatland LUCs at Tier 2 reporting levels.
- **Recommendation 1:** Since drained peatlands managed for peat extraction are significant CO_2 emission hotspots and have a positive feedback on climate change (with a probable increase in CO_2 emissions and projected increasing temperatures), they should be targeted for rewetting as a climate change mitigation strategy.

- **Observation 2:** Within the NEROS network of rewetted sites, rewetting actions (drain blocking) have been highly successful in raising the water table to close to or above the soil surface, even in the most degraded ecosystems. Maintaining high water table levels is a challenge across large sites (e.g. thousands of hectares of industrial cutaways) and for sites with little potential to establish dams (e.g. elevated dry sites). Moreover, seasonal and inter-annual variations in water table levels still prevail, depending on weather conditions but are buffered by certain vegetation types.
- **Recommendation 2:** While each rewetted site brings its own challenges, rewetting methods should be developed and implemented after careful site assessment. In all cases, the primary effort should be in the preparation of the site to raise the water table and keep it close to the surface; this is critical for the successful return of hydrological functioning within a peatland.

- **Observation 3:** Rewetting can bring back peat-forming vegetation within a short timeframe (< 10 years) and this period is shortened in less damaged sites, such as drained-only raised bogs. Vegetation species most characteristic of intact raised bogs

are present to some degree on such sites (subject to modest degradation), and rewetting actions (drain blocking) have been highly successful in raising the water table to close to or above the soil surface and crucially maintaining it at high levels over time.
- **Recommendation 3**: Drained-only sites or bogs that have suffered only modest cutting on the margins should be priority sites for rewetting activities to bring back the unique biodiversity associated with such ecosystems.

- **Observation 4**: Rewetting can provide benefits in terms of reducing GHG emissions for climate regulation, and the long-term monitoring in this study has demonstrated that it is a rapid strategy to mitigate climate change by either decreasing high CO_2 emissions or, for the better sites, returning the C sequestration function characteristic of natural bogs. However, this capacity clearly depends on site characteristics and not only on previous land use management.
- **Recommendation 4:** Nutrient-poor organic soils (under either peat extraction or grassland) have been identified as priority sites that can provide the greatest benefits not only in terms of reducing GHG emissions relative to their drained state but also with the potential to sequester C in the long term.

- **Observation 5**: In the NEROS network, we have identified "drained-only bogs" as the most optimal rewetted site type, which provides benefits for both biodiversity and climate regulation.
- **Recommendation 5**: With high biodiversity provision, avoided CO_2 emissions and high areal coverage, drained-only sites, which include most domestic extraction bogs (where a significant area of high bog remains), should be targeted for rewetting so that Ireland can deliver on both biodiversity and climate targets and to facilitate its legal requirements under EU directives and international conventions.

- **Observation 6**: Difficult sites have been identified within this study where rewetting has failed to return ecosystem functions, be it in space or in time. This was because the site might be very large and heterogeneous, for example large industrial cutaway peatlands. Rapid large-scale rewetting can permit a mosaic of habitats, which may not all be C sinks but will contribute to biodiversity. Another challenge to a quick return of natural ecosystem functions may arise if there is an intensive change in environmental conditions (e.g. the site was dry for a long time) or if the site includes material from previous land use, for example the brash left in rewetted clear-felled forestry sites, which leads to increased CO_2 emissions to the atmosphere as well as via aquatic pathways.
- **Recommendation 6**: In the case of large industrial cutaways, rehabilitation projects aiming at re-establishing vegetation on stabilised peat should take cognisance of future possible rewetting options (in the short and long term). This requires on-going monitoring of both hydrology and vegetation dynamics to evaluate the need for additional work to correct undesired successional and hydrological outcomes as well as knowledge of cutaway land surroundings (e.g. doubling as floodplains). Similarly, management of rewetted clear-felled forested peatlands should ensure that necessary interventions during the early years after initial rewetting/restoration works include (1) regular monitoring of water table levels, (2) appropriate management of the catchment to maintain water table levels close to the surface, and (3) the removal of all felled material (brash) from rewetted/restored forestry sites.

- **Observation 7:** Peat soils cover more than 20% of the country and so far rewetting/restoration has been confined to the designated network of raised bogs. A national strategy for rewetting *all* types of degraded peatlands should be established to select the best sites to maximise a reduction in C losses and potential for C sequestration and to increase biodiversity benefits. This requires information on biological and physical attributes, management regime, conservation objectives if present, etc., as well as local knowledge from all stakeholders.
- **Recommendation 7**: High-resolution maps of Irish peatlands under various management/land uses and disturbance regimes, showing their current characteristics and rewetting/restoration potential, should be developed to target priority sites for biodiversity and/or climate benefits. Meanwhile a database of all rewetted/restored peatlands and organic soils in Ireland should be established by collating all available monitoring data.

8 Conclusions

This study has highlighted the climatic benefits from rewetting degraded peatlands in terms of reduced GHG emissions, the return of the C sequestration function characteristic of natural (non-degraded) peatlands in many cases, and increased biodiversity provision. However, rewetting of degraded peatlands is a major challenge and can be a balancing act between benefiting biodiversity and/or climate. Nevertheless, in seeking to deliver on the sustainable management of our peatlands, as envisaged in the National Peatlands Strategy, and also to abide with legal requirements, it is essential that the synergy potential of the climate–biodiversity nexus is exploited and that degraded peatlands and organic soils are successfully rewetted and/or restored.

9 Peer-reviewed Publications from the NEROS Project

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Abbreviations

C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CP2	Second Commitment Period of the Kyoto Protocol
EF	Emission factor
EIV	Ellenberg indicator value
EPA	Environmental Protection Agency
EU	European Union
GHG	Greenhouse gas
HQ	Habitat quadrat
IPCC	Intergovernmental Panel for Climate Change
LUC	Land use category
N	Nitrogen
NHA	National Heritage Area
N_2O	Nitrous oxide
NEE	Net ecosystem exchange
PFT	Plant functional type
SAC	Special Area of Conservation
SWI	Shannon–Wiener Index
UNFCCC	United Nations Framework Convention on Climate Change
VQ	Vegetation quadrat
WDR	Wetland drainage and rewetting

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Networking Monitoring Rewetted and Restored Peatlands/Organic Soils for Climate and Biodiversity Benefits (NEROS)

epaResearch
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Authors: Florence Renou-Wilson, David Wilson, Caítlin Rigney, Ken Byrne, Catherine Farrell and Christoph Müller

Ireland contains large areas of peatlands that constitute some of the most ecologically diverse habitats in the country. In natural peatlands, permanently waterlogged conditions prevent the complete decomposition of dead plant material leading to the accumulation of carbon rich peat. However, less than 20 % of the original peatland area is considered to be worthy of conservation, being drained, cutover, industrially cutaway, afforested or intensely managed for grazing. In addition, the contribution of these degraded bogs to our national greenhouse gas (GHG) budgets is an increasing concern.

Identifying pressures

A field-based study was conducted that simultaneously quantified both biodiversity and climate mitigation benefits (i.e. GHG fluxes) across a rewetted peatland land use category network (NEROS). The land use categories (LUCs) monitored were forestry (on nutrient-poor soils), grassland and peat extraction (domestic cutover and industrial cutaway on nutrient-poor and nutrient-rich soils). Drained sites were also monitored for comparison purposes.

The findings demonstrated that the environmental and management variables present prior to rewetting can influence species composition and, therefore, the regeneration of species typical of natural sites. This in turn will affect the climate benefits from rewetting degraded peatlands in terms of potential for GHG emissions reduction and in some cases, the return of the carbon sequestration function characteristic of natural peatlands.

This study found that rewetting can bring back peat forming (i.e. carbon sequestering) vegetation within a short timeframe (<10 years) and this period is shortened in less damaged sites, such as drained-only raised bogs.

Such synergy between GHG emissions saving and biodiversity may not be achieved at other sites and therefore the best outcomes should be prioritised. For example, high carbon dioxide (CO_2) emissions can be avoided from rewetting industrial cutaway where typical raised bog biodiversity may not return. Meanwhile, rewetting previously afforested bogs remains a major challenge from both biodiversity and climate perspectives.

Informing policy

This report is opportune as it informs on the delivery of sustainable management of one of the last natural resources in Ireland, as envisioned in the 2015 National Peatlands Strategy.

Providing high biodiversity and avoiding CO_2 emissions, drained-only sites, which includes most domestic cutover bogs should be targeted for rewetting so Ireland can deliver on both biodiversity and climate targets and facilitate its legal requirements under EU Directives and International conventions. In addition, the findings from this research suggest that since drained peatlands managed for peat extraction are significant CO_2 emission hotspots and have a positive feedback on climate change, they should be also targeted for rewetting as a climate mitigation strategy.

Developing solutions

The rewetting of degraded peatlands is a major challenge and can be a balancing act between benefiting biodiversity and/or climate. Having taken full cognisance of the potential areas of each land use category, the findings from this research suggest that rewetting of drained only cutover bogs and industrial cutaway peatlands should be prioritised to maximise biodiversity provision and climate change mitigation.

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