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PeatGHG - Survey of GHG Emission and Sink Potential of Blanket Peatlands

Authors: Gerard Kiely, Paul Leahy, Philip McVeigh, Ciaran Lewis, Matteo Sottocornola, Anna Laine and Ann-Kristin Koehler

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

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EPA RESEARCH PROGRAMME 2014–2020

PeatGHG – Survey of GHG Emission and Sink Potential of Blanket Peatlands

(2012-CCRP-MS.9)

Prepared for the Environmental Protection Agency

by

University College Cork and the Waterford Institute of Technology

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Executive Summary

Throughout the Holocene, northern latitude peatlands have been a persistent net sink of atmospheric carbon dioxide (CO_2), a persistent source of atmospheric methane (CH_4) and a persistent source of carbon (C) in the form of dissolved organic carbon (DOC) in surface/subsurface runoff to rivers. That said, such peatlands have accumulated about one-third of the world's estimated total soil carbon pool in only 3% of the global land area. This means that the sink of CO_2 has exceeded the sum of the source (emission/loss) of CH_4 and DOC, thereby resulting in the sequestration of carbon in peatlands over the millennia, as pristine peatlands are considered to be a small annual sink for carbon. The dynamics and the interannual variation in the three components of carbon balance (budget) of pristine peatlands is considered to be fragile and potentially at risk from a changing climate. A changing climate potentially threatens the ability of peatlands to continue to sequester carbon and additionally creates the risk that appreciable amounts of stored peatland carbon could be released to the atmosphere. A wetter climate is likely to release greater amounts of both CH_4 and DOC than are emitted currently. A wetter climate, by raising the water table level, is likely to reduce the CO_2 exchange between the atmosphere and the peat surface. The exploitation of peatlands for agricultural purposes, for peat extraction and for afforestation, uses drainage technology that will lower the level of the water table significantly. A reduced water table changes not only the pattern of CO_2 and CH_4 exchange between the atmosphere and the peatland surface but also the hydrology and the magnitude of the DOC flux component of the carbon budget.

Peatlands originally occupied approximately 18% (or 1.2 million ha) of the land surface of Ireland, including approximately 12% (~700,000 ha) of Atlantic blanket bog (ABB). Approximately 21% of ABBs are considered to be now in pristine status. Ireland has the largest area of blanket bogs in Europe, highlighting the need for Ireland's ABB as an ecosystem to be conserved.

Multi-year carbon flux (CO_2, CH_4 and DOC) measurements of pristine peatlands are rare (three international sites are reported in the literature). They show a large interannual variation in the peatlands' carbon balance, with generally a small net uptake or sequestration of carbon.

Glencar, County Kerry, is the site of a pristine ABB. In the summer of 2002, the Hydromet Research Group in University College Cork set up the first eddy covariance flux tower in Ireland for the purpose of measuring the fluxes of CO_2, CH_4 and DOC. Here we report on 10 years of measurements. For the 10 years 2002–2011, the annual flux of CO_2, known as the net ecosystem exchange (NEE), ranged from −0.32 to −0.79 $t\,C\text{-}CO_2\,ha^{-1}\,yr^{-1}$ with a mean annual flux of −0.5 $t\,C\text{-}CO_2\,ha^{-}1\,yr^{-1}$ (i.e. uptake or sink). Note that a negative flux means uptake or sequestration in the meteorological sign convention. For the 6 years 2003–2008, the annual flux of CH_4 ranged from +0.036 to +0.046 $t\,C\text{-}CH_4\,ha^{-1}\,yr^{-1}$ with a mean annual flux of +0.041 $t\,C\text{-}CH_4\,ha^{-1}\,yr^{-1}$ (i.e. a source). For the 6 years 2003–2008, the annual flux of DOC ranged from +0.131 to +0.165 $t\,C\text{-}CH_4\,ha^{-1}\,yr^{-1}$ with a mean annual flux of +0.140 $t\,C\,ha^{-1}\,yr^{-1}$ (i.e. a source). Summing the three components of the carbon budget over the 6 years, we found that for 4 of the 6 years the site was a sink for carbon in the range of −0.241 to −0.656 $t\,C\,ha^{-1}\,yr^{-1}$ and in the 2 source years the magnitudes were +0.028 and +0.086 $t\,C\,ha^{-1}\,yr^{-1}$. The 6-year average annual carbon uptake at Glencar was −0.297 $t\,C\,ha^{-1}\,yr^{-1}$, which compares with −0.215 $t\,C\,ha^{-1}\,yr^{-1}$ at Mer Bleue (Canada) and −0.271 $t\,C\,ha^{-1}\,yr^{-1}$ at Degerö Stormyr (Sweden).

Relative to other ecosystems, this blanket bog has a NEE of approximately −0.5 $t\,C\text{-}CO_2\,ha^{-1}\,yr^{-1}$ in comparison with a NEE in Irish grasslands of approximately −3 $t\,C\text{-}CO_2\,ha^{-1}\,yr^{-1}$ and a NEE in Irish forestry of the order of −10 $t\,C\text{-}CO_2\,ha^{-1}\,yr^{-1}$. To enable the protection of pristine blanket peatlands, a deeper understanding is required of the dynamics of the components of the carbon budget with a view to modelling future climate change impacts.

1 Introduction

1.1 Aims and Objectives

The aims of this work were:

- to review the literature on carbon fluxes primarily in pristine and degraded blanket peatlands;
- to quantify the carbon fluxes [carbon dioxide (CO_2), methane (CH_4) and dissolved organic carbon (DOC)] at the pristine blanket peatland in Glencar, County Kerry, over the decade 2003–2012;
- to make recommendations on the future research direction for greenhouse gas (GHG) fluxes for Irish peatlands in the context of the international project Integrated Carbon Observation System (ICOS).

1.2 Layout of Report

The PeatGHG project aimed to add value to a number of carbon studies previously carried out at the Glencar pristine blanket bog in County Kerry. It also aimed to summarise these studies into one report. Chapter 1 includes a literature review of the carbon fluxes of blanket peatlands, both pristine and degraded. Chapter 2 describes the site at Glencar, the field instrumentation for GHG flux studies and the data processing involved. Chapter 3 presents the results of fluxes of CO_2, CH_4 and DOC at Glencar. A discussion of these fluxes and the total carbon budget is presented in Chapter 4. Conclusions and recommendations are detailed in Chapter 5, which is followed by a bibliography of international literature.

1.3 Distribution and Characteristics of Blanket Bogs

Peatlands are wetlands with an organic soil layer of at least 30 cm, which may extend to 15–20 m (Clymo *et al.*, 1998; Turunen *et al.*, 2002). One of its notable features is that the water table remains close to the surface throughout the year. Peat consists of the remains of partially decomposed plants because the rate of plant production exceeds the rate of decay due to the waterlogged conditions in peatlands. This in turn allows the accumulation of carbon (C) in the form of peat (Moore and Bellamy, 1974), with an estimated long-term ability of peatlands to sequester carbon of the order of 20–30 $g\,C\,m^{-2}\,yr^{-1}$ (Gorham, 1991; Turunen *et al.*, 2002; Turunen *et al.*, 2004), making them an important ecosystem for moderating atmospheric CO_2 concentrations. Throughout the Holocene, the impact of northern peatlands on climate radiative forcing has been a net cooling of up to 0.5 $W\,m^{-2}$, when both the uptake of CO_2 and the emission of CH_4 are considered (Frolking and Roulet, 2007). However, disturbance of peatlands by drainage, land use changes, extraction and fires, combined with climate change, can potentially convert peatlands into sources of carbon (Holden, 2005).

Northern latitude peatlands, i.e. those peatlands that occur at latitudes higher than 45° N, cover relatively small areas of the globe, equivalent to about 3% of the terrestrial land area. However, they contain nearly one-third of the terrestrial soil organic carbon (SOC) stock (Gorham, 1991; Turunen *et al.*, 2002), which would amount to 25–50% of the carbon that is currently present in the atmosphere as CO_2 (Frolking and Roulet, 2007; IPCC, 2007).

In Ireland, peat soils cover between 17% and 21% of the national land area (Figure 1.1) (Hammond, 1981; Connolly *et al.*, 2007; Eaton *et al.*, 2008; Connolly and Holden, 2009, 2014) and their SOC stock was estimated by two studies to be 53% and 62% of the national SOC stock (Tomlinson, 2005; Eaton *et al.*, 2008).

Peatlands are classified as bogs and fens according to their ecohydrology. Bogs are ombrotrophic peatlands, i.e. they depend on precipitation and aerial deposition for the supply of water, nutrients and minerals, whereas fens, or minerotrophic peatlands, are mainly reliant on groundwater (Gore, 1983). Bogs can be further divided into raised and blanket bogs according to their development. Raised bogs are dome-shaped masses of peat occupying former lakes or shallow depressions and their formation is a continuous development after a fen stage (Foss *et al.*, 2001). The development of blanket bogs is mostly independent of basins or topographic features where water collects; they simply blanket the landscape as the name suggests (Foss *et al.*, 2001). Blanket bogs can further be divided into Atlantic and Montane bogs depending on whether their altitude is above or below 200 metres above sea level (m asl) (Foss *et al.*, 2001). Blanket bogs account for less than 3% of the world's peatlands, with the blanket bogs in Ireland and the UK forming the largest single contribution, of about 10–15% (Foss *et al.*, 2001; Eaton *et al.*, 2008). The peatland in this study is an Atlantic blanket bog in the south-west of Ireland.

The development and active spread of blanket bogs in Britain and Ireland was between 5100 and 3100 BP (before present) (Tallis, 1998), whereas the widespread blanket bog initiation in the south-west of Ireland was probably rather late, ranging from 3260 BP to the early first millennium BP (O'Connell, 1990). Although the exact sequence of events leading to the widespread development of blanket bogs in Ireland is still not well understood, the phenomenon is thought to have been aided by woodland and scrub clearance carried out by early farmers (O'Connell, 1990). Once blanket bogs began to form, the process was greatly aided by the prevailing cool and wet climate. Within Ireland, blanket bogs are confined to areas with high annual rainfall exceeding 1250 mm and number of rain days per annum (i.e. > 2.0 mm d^{-1}) exceeding 200 (Hammond, 1981; O'Connell, 1990), which maintains waterlogged conditions on the ground. After climate, the most important environmental factors influencing the development of blanket bogs are topography and geology. Blanket bog development rarely takes place in areas where the slope exceeds 25° from the horizontal and it is best developed on areas of unyielding, base-poor bedrock (O'Connell, 1990; Tallis, 1998). Therefore, while climatic factors and time-dependent soil processes form the background against which the spread of blanket bog took place, it is argued that human impact played a major role in its wide-scale expansion (O'Connell, 1990).

1.4 Literature Review – Carbon Fluxes in Blanket Peatlands

The interest in the GHG balance in peatland ecosystems had been largely ignored until recently [e.g. not included in the European Projects CarboEurope (2005) and NitroEurope (2008)]. The recent interest (e.g. special task in WP2 – Critical Processes of the European Project GHG-Europe) has arisen from the recognition that a large soil carbon reservoir is stored in peat (an estimated one-third of the global soil carbon pool; Gorham, 1991). This is potentially available to the atmosphere if decomposition exceeds production (a possibility with climate change) (Bubier *et al.*, 1995). In European large-scale GHG balance studies, peatland flux studies are considered from only a few countries (Finland, Germany, the Netherlands, Sweden and the UK; Luyssaert *et al.*, 2012) and this is likely to be because of the paucity of data.

Peatlands occupy a relatively small fraction of the Earth's land area, but they store a globally important carbon stock. Undisturbed peatlands currently act as a weak carbon sink (~0.1 pg C yr^{-1}), a moderate source of methane (CH_4; ~0.03 pg CH_4 yr^{-1}) and a very weak source of nitrous oxide (N_2O; ~0.00002 pg N_2O–N yr^{-1}). Anthropogenic disturbances, primarily drainage (10–20% of global peatlands), result in net CO_2 emissions, reduced CH_4 emissions and increased N_2O emissions, probably changing the peatland GHG balance to a carbon source (~0.1 pg C yr^{-1}), a 10% smaller CH_4 source and a larger (but still small) N_2O source (~0.0004 pg N_2O–N yr^{-1}) (Frolking *et al.*, 2011).

Peatlands are wetland ecosystems where the rate of production of organic matter exceeds its rate of decomposition (Bubier *et al.*, 1995). This imbalance is due to the inhibition of decomposition processes by the high water table and consequent anoxic conditions, and results in the accumulation of partly decomposed organic material as peat (Moore and Bellamy, 1974).

The development of northern latitude peatlands is closely related to regional climate controls on precipitation, evaporation and temperature (Payette and Rochefort, 2001). The carbon exchange is thus strictly connected to the water and energy exchanges. The water budget in northern peatlands influences the ecosystem carbon sequestration (Lafleur *et al.*, 2003) and the partitioning of the available energy (Brutsaert, 2005) as well as affecting the soil chemistry (Laine *et al.*, 1995) and the vegetation composition (Belyea and Clymo, 1998, 2001).

Climate change (increased winter precipitation and decreased summer precipitation) in northern latitudes is predicted to perturb the water and energy budgets (IPCC, 2001). As a result, climate change in northern peatlands is expected to affect the hydrology (Roulet *et al.*, 1992), the vegetation composition (Weltzin *et al.*, 2003) and the carbon balance (Updegraff *et al.*, 2001; Basiliko *et al.*, 2005) of peatlands. Nevertheless, the response of the carbon budget to climate change is difficult to predict as a result of the complexity of the soil–vegetation–hydrology relationships that determine the carbon cycle in peatlands. Moreover, the heterogeneity of the microform structure of bogs, due to their high spatial variation in water table, vegetation composition and chemical status, can complicate the synthesis of the response of the ecosystem as a whole to climate change (Strack and Waddington, 2007). Overall, carbon gain or loss depends on whether the transition is towards or away from the optimal conditions for carbon accumulation for that ecosystem, and this is mainly determined by the hydrological response (Dise, 2009).

In Ireland, blanket bogs comprise around 13% of the total land area, yet they contain between 21% and 36% of the national soil carbon stock (Eaton *et al.*, 2008; Xu *et al.*, 2011). Like raised bogs, blanket bogs are largely ombrotrophic peatlands, receiving water and nutrients mainly from precipitation, even if minerotrophic areas also occur in extensive blanket bogs (Tallis, 1998). They are important not only for carbon storage, but also in terms of biodiversity. These ecosystems are normally located over relatively flat or gently sloping terrain (Tallis, 1998). They tend to form in temperate maritime climates with consistently high rainfall (> 1200 mm per annum, > 200 wet days a year, with a wet day receiving at least 2 mm of rain in a day) combined with low evaporation rates, resulting in a ground surface that may remain consistently waterlogged (Lindsay, 1988; Moore, 1993). As a result of their proximity to the sea, these ecosystems also tend to have high sea-origin ion concentrations (Proctor, 1992; Tallis, 1998; Sottocornola *et al.*, 2009).

Blanket bog surfaces are typically a mosaic of various undulating microforms, which differ in terms of water table level (WTL), plant composition and chemical characteristics (Sottocornola *et al.*, 2009). Different vegetation communities support different CO_2 exchange dynamics, and therefore blanket bogs are likely to have different functional responses from other types of ecosystems that have been studied for such effects.

Other than by climate change, peatlands are threatened by an increase in disturbance, which typically implies some form of drainage. Drainage has a strong impact on the biogeochemical cycles and ecosystem functioning of peatlands (Waddington *et al.*, 2002), as it disrupts the close connection between the water and carbon cycles of these fragile ecosystems. In Ireland, peatlands cover between 17% (Eaton *et al.*, 2008) and 21% (Connolly and Holden, 2009) of the national land area, with blanket bogs being a large part of this, covering about 13% of the country and containing about 45% of the national soil carbon stock (Eaton *et al.*, 2008; Kiely *et al.*, 2008). Despite being worthy of conservation, only 21% of Irish blanket bogs remain in relatively pristine conditions (Foss *et al.*, 2001). This highlights the need to enhance current conservation strategies and define an action plan for peatland sustainable management (Douglas, 1998; Bullock *et al.*, 2012).

In the last 10 years, research on carbon fluxes and budgets has provided information on the carbon sequestration and functioning of some Irish peatlands. In particular, the Atlantic blanket bog of Glencar (County Kerry) has been the object of intensive GHG flux studies, which identified it as a small sink of CO_2, sequestering an annual average of $55\,g\,C\text{-}CO_2\,m^{-2}$ (Sottocornola and Kiely, 2010a), which, added to the loss of methane and DOC in the streams, resulted in a carbon balance uptake average of $30\,g\,C\,m^{-2}\,yr^{-1}$ (Koehler *et al.*, 2011). The carbon and CO_2 annual balances in this Atlantic blanket bog were reported to be very similar to those of boreal raised bogs and oligotrophic fens, although both gross ecosystem production and respiration were lower (Sottocornola and Kiely, 2010a). Moreover, these annual averages were the result of very wide interannual variation, ranging from a net annual sink of $66\,g\,C\,m^{-2}$ to an annual source of $9\,g\,C\,m^{-2}$, and indicate that the optimum meteorological conditions for the peatland growth are moderate values rather than extremes in terms of both temperature and precipitation (Sottocornola and Kiely, 2010a; Koehler *et al.*, 2011).

In addition to Glencar, the carbon balances of other near-intact Irish peatlands have been studied for a short time using chamber technology in the past few years and they showed small annual carbon losses (Wilson, 2008). Short-term studies have also been carried out in disturbed Irish peatlands, revealing a wide range of carbon balances, from high losses in rewetted wetlands (e.g. Wilson *et al.*, 2009) to uptake in afforested cutaway peatlands (Byrne and Farrell, 2007).

Unlike other studies on peatland carbon fluxes in Ireland, the investigation of the carbon cycle and balance in Glencar has been achieved through the short-term use of chamber technology and 10 years of continuous non-invasive eddy covariance (EC) measurements. Such long-term and large-scale EC measurements (Sottocornola and Kiely, 2010a,b) supported other types of investigations, such as the chamber measurements, in validating the spatial variation through upscaling exercises (Laine *et al.*, 2006). Such studies also created a baseline that would be of importance in comparing the carbon balances from vegetation classes, identifying the different degrees of peatland disruption, with a long-term reference record.

A study completed by Yurova *et al.* (2007) at a mire in Sweden found that CO_2 uptake was controlled by interactions between WTL and air temperature. It noted that higher air temperatures (>15°C) and a WTL that was neither too low nor too high resulted in conditions that were optimal for high net ecosystem exchange (NEE). In another study, by Lindroth *et al.* (2007), at four mires at different latitudes in Sweden

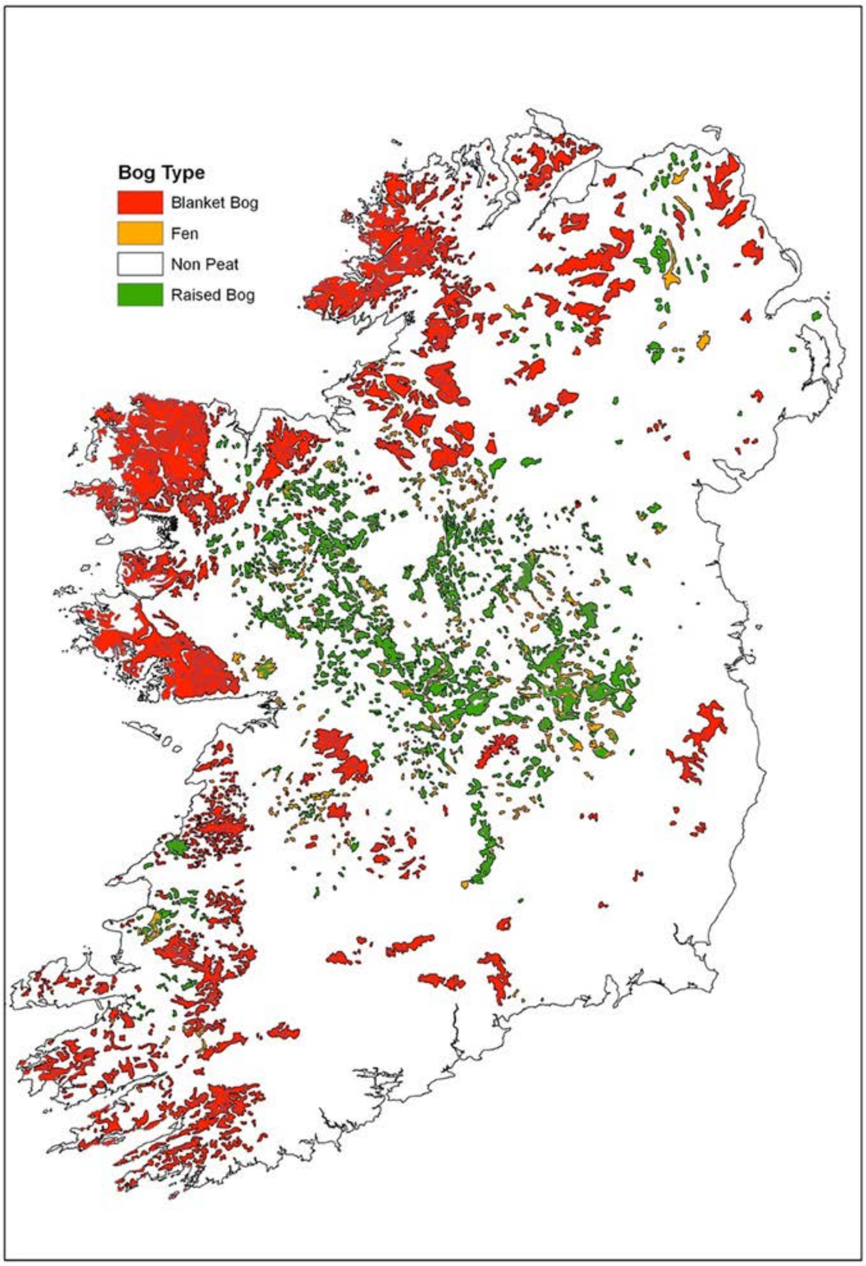

Figure 1.1. Map of the distribution of blanket bogs, fen and raised bogs in Ireland. Taken from Hammond (1981).

and Finland, findings were similar in that WTL and temperature explained most of the variance in NEE. In addition to this, cooler temperatures and longer daylight hours at northerly locations were found to be beneficial for higher NEE during summer.

Previous studies at an Atlantic blanket bog in Glencar, south-west Ireland, by Sottocornola and Kiely (2005, 2010a) and Koehler *et al.* (2011) demonstrated that it is a small sink for direct CO_2. It was found to have annual carbon and NEE balances similar to boreal raised bogs, but with lower gross ecosystem production (GEP) and ecosystem respiration (ER). At the same location, Laine *et al.* (2009) reported that high water-level conditions favoured ecosystem acting as net sources of CO_2 and, the wetter the conditions, the lower the ecosystem CO_2 sink.

2 Materials and Methods

2.1 Site Description

The measurement site is an Atlantic blanket bog situated near Glencar, County Kerry, south-west Ireland (Killorglin-Glencar, IE-Kil in the European Fluxes Database Cluster; latitude, 51° 55’ N; longitude, 9° 55’ W), approximately 150 m asl on sandstone bedrock. In the centre of the bog, the upper acrotelm peat layer is mainly sedge peat with a bulk density of 0.05 g cm^{-3} and a porosity of 95%, with peat depths ranging between 2 and 5 m (Lewis *et al.*, 2012). A stream draining the bog with a catchment area of about 74 ha lies to the south, with 85% of the catchment area relatively intact blanket bog and 15% on a hill slope that consists of alternating grazed patches of grassland and drained peaty soils (Koehler *et al.*, 2011). See Figure 2.1.

The bog is spatially heterogeneous, consisting of an assortment of microforms that differ in relative elevation, plant composition and WTL (Sottocornola *et al.*, 2009). These were grouped into four categories based on relative elevation: hummocks, high lawns, low lawns and hollows (Laine *et al.*, 2006; Sottocornola *et al.*, 2009). The difference in height between the highest and lowest microforms is typically 20 to 40 cm. Hollows are 50 to 300 cm oblong depressions covered by standing water for most of the year. The division of microforms within the EC footprint was estimated to be 6% hummocks, 62% high lawns, 21% low lawns and 11% hollows (Laine *et al.*, 2006).

Vascular plants account for 30% of land coverage during summer (Sottocornola *et al.*, 2009). Of these, the species most commonly encountered are *Molinia caerulea* (L.) Moench (purple moor grass), *Calluna vulgaris* (L.) Hull (common heather), *Erica tetralix* L. (cross-leaved heath), *Narthecium ossifragum* (L.) Huds. (bog asphodel), *Rhynchospora alba* (L.) Vahl (white beak-sedge), *Eriophorum angustifolium* Honck. (common cotton grass), *Schoenus nigricans* L. (black-top sedge) and *Menyanthes trifoliata* L. (buckbean).

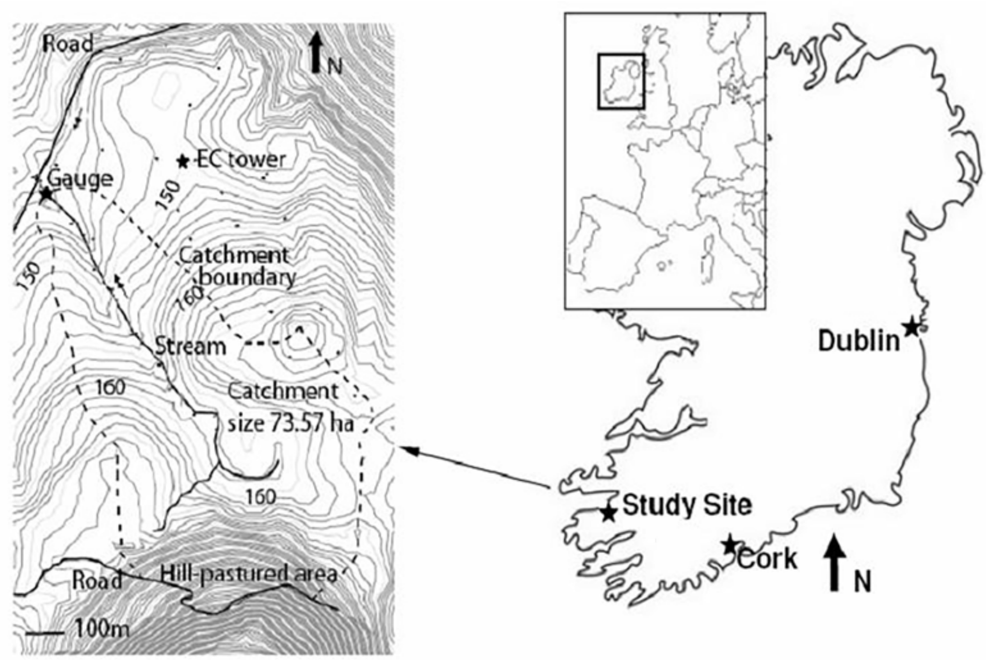

Figure 2.1. Site layout and location map. The peatland site is located about 120 km west of Cork City. The catchment boundary is shown with a dashed line and the bog stream is shown in a solid line. The stream is gauged at the northern side. EC tower refers to the location of an eddy covariance tower. The site is named Killorglin-Glencar (IE-Kil) in the European Fluxes Database Cluster and is at latitude 51° 55’ N; longitude 9° 55’ W. From Koehler (2012).

Bryophytes are not so widespread, accounting for about 25% of surface cover. The principal species here are *Racomitrium lanuginosum* (Hedw.) Brid. (woolly hair-moss) and bog mosses (*Sphagnum* spp.), both occurring in similar quantities (Sottocornola *et al.*, 2009).

2.2 Instrumentation and Methods for Measuring CO_2 Fluxes

In the summer of 2002 we constructed a 3-m-high scaffold tower in the Glencar bog, approximately 500 m from the roadway. Initially we supplied power to the instruments using solar panels but after the first winter we changed to mains power. We used the latter as feed to a charger, which trickle-charged two large batteries (total 180 Ah) that provided 12 volt power to all the instruments. Meteorological and environmental parameters were recorded at various levels either above or below ground. Micro-meteorological measurements were all made at a height of 3 m. All above ground instruments were located at the 3-m tower, details of which are outlined in Sottocornola and Kiely (2010a).

The principal meteorological and environmental parameters measured were net solar radiation (Rn), air and 5-cm-depth soil temperatures (T_{air} and $T_{soil\,5cm}$, respectively), relative humidity (Rh), precipitation (ppt), water table level (WTL), atmospheric pressure (P_a) and soil heat flux (G). These variables were recorded every minute and then averaged over 30-minute periods using a CR23X datalogger (Campbell Scientific, UK). Wind speed (WS) and direction (WD) were computed using a sonic anemometer (see next paragraph). The one-sided leaf area index (LAI) was also measured at different time intervals using a PAR/LAI Ceptometer (LP-80 AccuPAR, Decagon devices, Inc., USA).

The micro-meteorological parameters that were measured using a 3D sonic anemometer included *U*, *V*, *W* (horizontal, lateral and vertical WSs, respectively) and the speed of sound, in addition to CO_2 and H_2O mass densities from an open-path infrared gas analyser (LI7500 IRGA, Li-COR, USA). These variables were recorded at 10 Hz, and the use of a running mean gave 30-minute block averaged fluxes. The logging of EC data was with a CR23X until September 2009, after which a CR1000 datalogger (both by Campbell Scientific, UK) has been used continuously.

The 3-m measurement tower was centrally located on the bog with an uninterrupted fetch of at least 300 m radius, which was relatively flat in all directions. A footprint analysis following Hsieh *et al.* (2000) found that the footprint extended to around 300 m from the tower during unstable daytime conditions, and 750 m during stable night-time conditions.

2.3 Instrumentation and Methods for Measuring CH_4 Fluxes

To facilitate the chamber CH_4 flux measurements, 28 plots were selected from which 24 were equipped with constant collars, while floating chambers were used for the remaining four plots. To relate the CH_4 flux to environmental conditions, T_{air}, soil temperature at different depths (5-cm, 10-cm, 20-cm and 30-cm depth) and WTL adjacent to each sample plot were recorded simultaneously with the CH_4 readings. Air and soil temperature were measured using thermocouples (fine wire Type K thermocouple, Radionics Ltd, Ireland). The WTL was determined from perforated PVC pipes protruding 10 cm above the peat surface to account for standing water above the surface. For the majority of hollow plots a different technique was used, as the ground was too soft and wet to keep the PVC pipes in place. Instead, bamboo sticks were inserted in the peat that reached down to the underlying, more solid ground of the bog and the WTL was marked at the day of installation. The absolute change between the mark and the WTL on the days of the CH_4 flux measurements was recorded.

The closed chamber method was used to estimate the flux of CH_4 from the peatland. CH_4 measurements conducted from August 2003 until September 2005 are described by Laine *et al.* (2007a). Further CH_4 chamber measurements were carried out at biweekly to monthly intervals during 2008. As a result of relatively mild winters with little frost, it was possible to sample all the year round. Four replicate plots were sampled for each of the three microforms: hummock, high lawn and low lawn. Unlike as was the case in Laine *et al.* (2007a), the hollows were further divided into hollows with a mud bottom, hollows covered by mosses only, by vascular plants without *M. trifoliata* or by vascular plants including *M. trifoliata* (Koehler, 2012). Four replicates were sampled for each defined hollow type. As it was not possible to install collars at four of the hollow plots, the chamber size was reduced from 0.6 m × 0.6 m × 0.25 m to 0.3 m × 0.3 m × 0.3 m to use floating chambers. Apart from the size, the remaining chamber features and additional measurements of soil temperature at different depths and water table depth for each plot were the same as used by Laine *et al.* (2007a). Accordingly, the same non-linear regression approach as in Laine *et al.* (2007a) was used to reconstruct CH_4 fluxes for the period 2003–2008:

$$CH_4 = (c + d \times \mathrm{WTL})(\exp(b \times T_{soil\ 20cm})) \quad \text{(Equation 2.1)}$$

where *b*, *c* and *d* are parameters, WTL is water table level and $T_{soil\ 20cm}$ is the soil temperature at 20-cm depth. Equation 2.1 was parameterised for each sample plot separately based on the periodic chamber measurements between 2003 and 2005 and during 2008, and then used to estimate the CH_4 flux for the whole period 2003–2008. If the linear function describing the relationship of the WTL to CH_4 flux did not increase the explanatory power of Equation 2.1, it was replaced with a constant *a*. Four plots had to be taken out of the final flux calculation, as the fit of the non-linear regression was not satisfactory; nevertheless, at least three replicates were available for each microform. For the CH_4 flux integration, a continuous (30-minute) time series of $T_{soil\ 20cm}$ and WTL for each sample plot were reconstructed from the $T_{soil\ 20cm}$ and *WTL* continuously measured at the meteorological station. The annual CH_4 flux was calculated through an upscaling based on the known average distribution of the microforms around the EC tower (as defined by Laine *et al.*, 2006). The standard error of the average annual CH_4 flux from each microform type was computed and weighted according to the microform distribution to estimate an error for the annual CH_4 fluxes (Laine *et al.*, 2007a).

2.4 Instrumentation and Methods for DOC Fluxes

At the northern outfall of the catchment (close to the road and to Dromalonhurt bridge), stream height was recorded every 30 minutes starting 1 January 2007 using a pressure transducer (1830 Series, Druck Limited, UK) (Figure 2.2). Stream height was converted to discharge using a site-specific rating curve:

$$Q = 0.685 \times s^{1.79}, \text{ number of measurements} = 10, \; r^2 = 0.995 \quad \text{(Equation 2.2)}$$

where *Q* is discharge in $m^3 s^{-1}$ and *s* is stream height in m. The total discharge was calculated by integrating the 30-minute discharge data. The rating curve was established from manual measurements of instantaneous discharge carried out at a range of stream heights using an OTT current meter (OTT Messtechnik GmbH & Co KG, Germany). The error related to the discharge calculation was determined from the standard error of the rating curve and an error of 5% was included to account for drainage basin area uncertainties (Fraser *et al.*, 2001).

Continuous measurements (30-minute intervals) of DOC began in January 2007 using an S-can spectro::lyser (scan Messtechnik GmbH, Austria). The instrument is constantly immersed in the stream at the gauge site (Figure 2.2) and works according to the measuring principle of ultraviolet–visible (UV-Vis) spectroscopy. The measured spectrum ranges from 200 to 735 nm and the absorbance is determined every 2.5 nm. The calculation of the DOC concentration is based on the inclusion of over 80 wavelengths, some to actually calculate the concentration but most for correction of turbidity. The spectro::lyser's lenses were automatically cleaned before each 30-minute measurement by a puff of pressurised air and manually cleaned every 1–2 weeks. Additionally, the spectro::lyser readings were zeroed using distilled water approximately every 4 months. These precautions reduced the drifting of the spectro::lyser as a result of environmental conditions. The drifting between two subsequent manual cleaning events (usually below 1 mg L^{-1}) and calibration was corrected assuming a constant linear drift over time. Moreover, as the automatic in-stream spectro::lyser is not specifically designed for peatland waters, its measurements were calibrated on a regular basis with results from wet chemical laboratory analyses. A 24-bottle auto-sampler (6712 portable sampler, Teledyne Isco, Inc., USA) was used approximately every 6 weeks from April to October 2007 to collect water samples at intervals of between 1 and 3 hours at the same location as the spectro::lyser. The auto-sampler was installed in the stream to monitor a range of flow conditions. DOC concentration in the water samples was measured in the laboratory using a TOC-V cpH (SHIMADZU Scientific Instruments, USA), which works according to an oxidative combustion–infrared method. Spectro::lyser measurements and laboratory analyses compared well during both dry periods and storm events regarding the

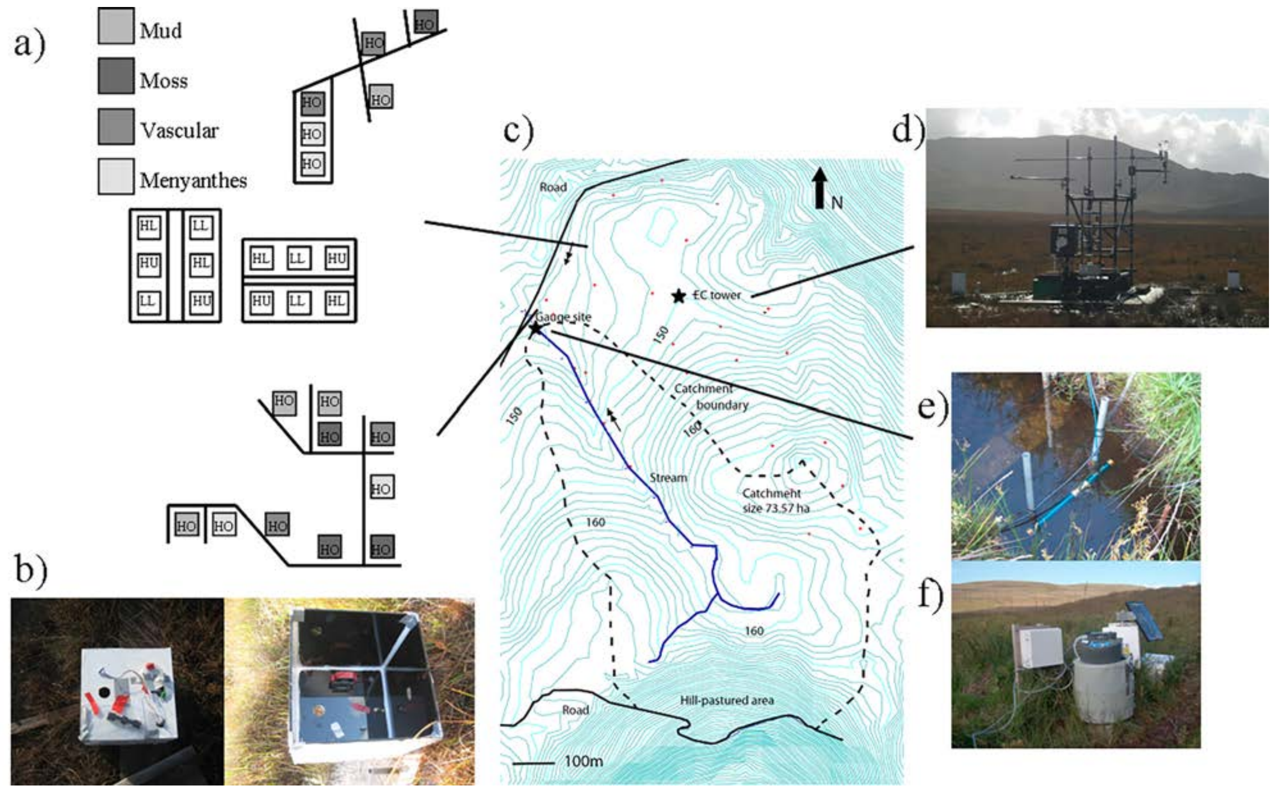

Figure 2.2. Overview of the site layout and instrumentations used for measuring the carbon fluxes and environmental parameters. (a) CH_4 measurement plan set out; (b) chamber for CH_4 measurements; (c) site layout map; (d) tower with EC system and meteorological measurement instruments; (e) spectroanalyser in the stream for DOC concentration measurements; and (f) bottle auto-sampler and stream monitoring station. HL, high lawn; HO, hollow (with different shading indicating the type of hollow); HU, hummock; LL, low lawn. From Koehler (2012).

general trend of DOC concentration, i.e. increase or decrease in concentration. A constant difference between laboratory and field measurements over the sampling time was observed, so the spectro::lyser measurements were corrected for linear drifting between consecutive bottle auto-sampler collections.

The DOC flux was computed as the product of DOC concentration and streamflow discharge. For the years 2003–2006, the measured stream height and DOC concentration were not available and were therefore modelled as follows. The monthly discharge was regressed against monthly precipitation (data 2007–08):

$$Q = precip \times 0.896 + 6.138,\ r^2 = 0.90,\ \text{RMSE} = 35.7 \quad \text{(Equation 2.3)}$$

where Q is discharge and *precip* is the monthly precipitation, both in mm.

The best relationship for DOC concentration was an S-shaped function of binned daily mean air temperature (T_{air} in °C) and daily mean DOC concentration (DOC in mg L^{-1}) (see Figure 2.3).

$$DOC = 3.763 + \frac{5.144}{1 + \exp(-0.6888 \times T_{air} + 7.387)},$$

$$r^2,\ \text{RMSA} = 0.63 \quad \text{(Equation 2.4)}$$

An error estimate for Equation 2.3 and Equation 2.4 was computed as described for the relationship between stream height and discharge (Equation 2.2) (Fraser *et al.*, 2001), resulting in a lower and upper estimate of the DOC flux for the period 2003–2006. To calculate the DOC flux for the period 2003–2006 the estimated daily DOC concentration was averaged over the month and multiplied by the estimated monthly discharge resulting in estimates of 12.6 ± 3.2 g C m^{-2} for 2007 and 15.8 ± 3.2 g C m^{-2} for 2008, compared with our measured values of 11.9 ± 1.2 and 15.0 ± 1.3 g C m^{-2} for 2007 and 2008, respectively.

Additionally, DOC concentration in precipitation was measured over a 1-year period (n = 7) with three

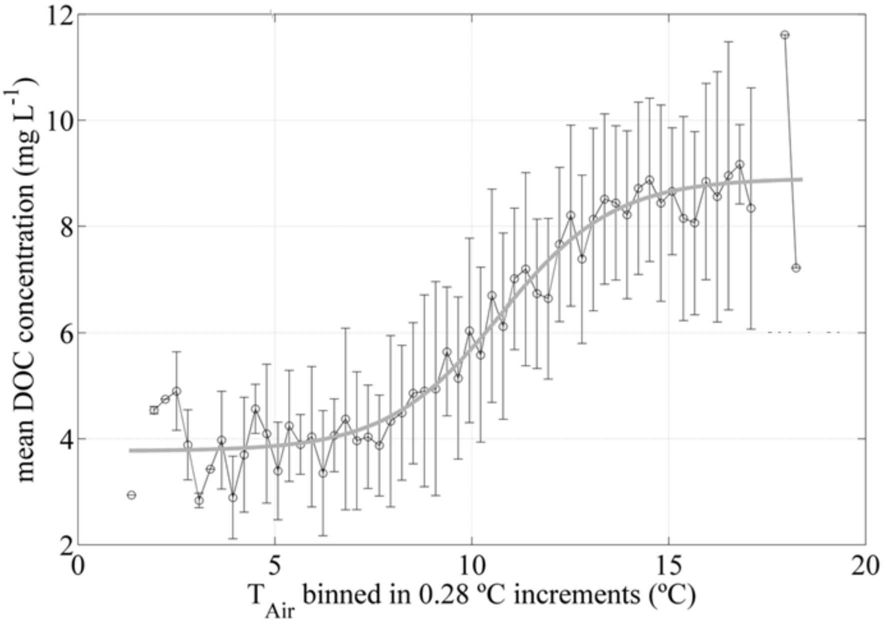

Figure 2.3. S-shaped relationship of binned mean daily T_{air} and corresponding mean daily DOC concentration. From Koehler (2012).

replicates each time using a funnel with an attached bottle. The bottles were left in the field for up to 3 days during a rainy period and were analysed for DOC concentration thereafter. The product of the mean DOC concentration over the 1-year period and the annual amount of precipitation was used to estimate the DOC input in precipitation for each year. For the stream water, a 24-bottle auto-sampler (6712 portable sampler, Teledyne Isco, Inc., USA) was used every 6–8 weeks and the samples were analysed for dissolved and total organic carbon using a TOC-V cpH (Shimadzu Scientific Instruments, USA). The flux of particulate organic carbon (POC), which is the difference between total and dissolved organic carbon, was estimated using the average percentage of POC calculated from the bottle auto-sampler results.

2.5 CO_2 Flux Data Processing

All data collected were added to a single file that included an entry for every half hour since the beginning of measurements. If no data were available, these entries were left empty and flagged for later gap filling. Data processing and filtering techniques used for the data from this site were very similar to those used previously, details of which can be found in Sottocornola and Kiely (2010a,b) and Koehler *et al.* (2011). Any variation on these approaches is described in this section. Filtering was mostly a result of the poor performance of the LI-7500 and sonic anemometer during precipitation events, or signal noise originating from very weak signals. The data are now published on the European Fluxes Database Cluster site under the site name of Killorglin-Glencar, IE-Kil (www.europe-fluxdata.eu).

The simplified model developed by Hsieh *et al.* (2000) was used to estimate the fetch length requirement (x_f) for reaching the 90% constant flux layer during neutral, stable and unstable conditions. Fluxes were discarded if x_f was more than 300 m away, which accounted for the removal of <1% of data based on the findings of Hsieh *et al.* (2000). Co-ordinate rotations are subject to larger errors as the rotational angle increases, especially when wind speeds are low and turbulence is high. Therefore, fluxes associated with unrealistic rotated u-values were removed. This accounted for the removal of only <0.1% of data when wind speeds were practically zero, typically at night-time.

As a final step, sensible (H) and latent (LE) heat fluxes were filtered based on a fixed linear fit with R_n, from which a fixed cut-off value above and below the line of fit was pre-determined. Cut-off values were 75 W m^{-2} for upper and lower H as well as upper LE, whereas the lower cut-off for LE was 60 W m^{-2}. Removal of H and LE in this way provided an unbiased approach for data removal throughout all the seasons, and most removal occurred during periods when R_n, and hence energy transfer, was ≈0. In both cases, this method accounted for less than 4% of overall filtering. The amount of good H-values remaining after filtering ranged between 58% (2011) and 80% (2004), whereas for LE it was between 53% (2009) and 78% (2004).

Similar filters were used for CO_2 flux data using a pre-determined fixed fit. For daytime fluxes, an exponential fit with photosynthetic active radiation (Q_{PAR}) was used, whereas a linear fit with $T_{soil\ 5cm}$ was used for night-time data. Alternatively, incoming solar radiation or T_{air} could have been used to give a nearly identical outcome.

Daytime data were filtered in two stages: first using non-density-corrected CO_2 fluxes to account for poor measurements, and second using density-corrected fluxes to account for poor corrections, which were mostly over-corrections (Webb *et al.*, 1980). For non-corrected data, the upper cut-off was 7 μmol m^{-2} s^{-1} and the lower was 5 μmol m^{-2} s^{-1}. For corrected fluxes, upper and lower cut-offs ranged from 1.5 to 4.5 μmol m^{-2} s^{-1} depending on the season. Removal in this way mainly accounted for periods when incoming solar radiation was near zero, resulting in a noisy CO_2 flux signal that had to be filtered.

Night-time data were filtered using only an upper cut-off of 0.5 μmol m^{-2} s^{-1}. Spurious results occurred across the whole temperature range because the EC method has difficulty measuring accurately at night (Aubinet, 2008). No friction velocity (u*) filter was applied because no clear correlation between flux magnitude and u* was apparent. The amount of good daytime fluxes remaining after filtering ranged from 44% (2009) to 68% (2004), whereas it ranged from 21% (2009) to 35% (2007) for night-time data.

The gap-filling techniques used for LE, H and night-time CO_2 fluxes were similar to those described in Sottocornola and Kiely (2010a,b). Daytime CO_2 fluxes were filled by relating the CO_2 flux to Q_{PAR} using the Mitscherlich formula, defined as:

$$F_{c(day)} = -24\left[1 - e^{\left(\frac{\alpha . Q_{PAR}}{-24}\right)}\right] + \gamma \qquad \text{(Equation 2.5)}$$

where α is the ecosystem quantum yield and γ is the daily respiration. Gap filling for daytime CO_2 fluxes was performed using a moving window of 5 days on either side of each day. This approach helped to ensure smooth seasonal transitions and more accurate curve fitting. Gap filling for all other fluxes used a fixed window covering the entire period of measurement. The uncertainty of NEE was estimated following Aurela *et al.* (2002) and Sottocornola and Kiely (2010a).

The partitioning of NEE of CO_2 along with the separate study of ER and GEP is necessary to evaluate the sensitivity of ecosystems to climate change (Barr *et al.*, 2007; Dunn *et al.*, 2007). To calculate ER, the Lloyd and Taylor (1994) exponential regression was used to model the daytime ER by considering night-time NEE to be ER, and applying a night-time-derived ER model to daytime, assuming that the temperature dependence is the same during day and night (Reichstein *et al.*, 2005). To calculate GEP, the following equation was used:

$$\mathrm{GEP} = \mathrm{ER} - \mathrm{NEE} \qquad \text{(Equation 2.6)}$$

The start and the end of the growing seasons were estimated as the first and last 3 consecutive days with a cumulative GEP > 3 g C-CO_2 m^{-2}.

3 Results

3.1 Meteorological Parameters

The 10 complete years of measurements between September 2002 and August 2012 in Glencar were characterised by a wide range of environmental conditions (see Figures 3.1 and 3.2 and Table 3.1). These years have seen some of the warmest months coupled with the wettest months and years as well as some of the coldest winters in the Irish National Meteorological Service (Met Éireann) national archives (http://www.met.ie/climate-ireland/rainfall.asp and http://www.met.ie/climate-ireland/surface-temperature.asp). This enables the weather conditions observed at the site to be put into the wider context of climate variability in the region.

Summer 2006 experienced the highest average seasonal temperatures (16.4°C) as well as the highest half-hourly temperature recorded in Glencar (27.9°C). During the winters of 2009/2010 and 2010/2011, temperatures across UK and Ireland dropped to record lows, with half-hour average temperatures as low as −11.1°C measured in Glencar during December 2010, in what was the second coldest Irish winter on record between 1961 and 2010 according to Met Éireann records. Monthly mean values of T_{air} at Glencar ranged from 3°C (December 2010) to 16°C (July 2006). Annual T_{air} mean values were lowest in 2010 at 9.8°C and highest in 2007 at 11°C, with an overall annual average of 10.5°C.

The 3 wettest years were 2008, 2009 and 2011, which were after the last data from Glencar reported by Sottocornola and Kiely (2010a,b). Summers were generally drier than winters, although August 2008 had the greatest amount of rainfall recorded in a single half hour, amounting to nearly 14 mm. Seasonal precipitation variance was quite high, whereby monthly values ranged from 42 mm (August 2003) to 520 mm (November 2009), the latter of which resulted in widespread flooding nationwide. The year 2009 was the wettest of the 10 years measured, with 2854 mm of rainfall, whereas 2010 was the driest at 2106 mm, with an overall 10-year average of 2467 mm. The year 2009 was also the wettest year on record nationally for the period 1941–2010 according to Met Éireann records.

The WTL follows a similar seasonal and annual pattern to that of precipitation; the WTL is generally higher (i.e. closer to the surface) in winter than summer. The interannual variation (IAV) in WTL was relatively high, from one of the highest annual mean levels in 2009 (–2.6 cm below the land surface) to the lowest in 2010 (–7.0 cm). Relative humidity (Rh) was typically lowest on average during the spring and early summer months, showing minimal IAV, being lowest during 2003 (81%) and highest in 2011 (83%). Latent heat (LE) during 2011 and 2004 were the highest recorded over the 10 years, averaging at 32.5 and 32.9 W m^{-2}, respectively. The opposite was found for 2003, having one of the highest WTLs, yet one of the lowest Rh rates. Monthly WTL varied from −13 cm to 0 cm and monthly Rh varied from 74% to 88%.

Monthly and annual totals or averages of the seven meteorological variables considered the most important for long- and short-term CO_2 exchange control are displayed in Figures 3.1 and 3.2 as well as in Table 3.1. Totals (for Q_{PAR} and precipitation) and averages (all other meteorological variables) for each month of each year were calculated along with monthly averages across all years. Data from the complete years 2003–2011 are presented as annual values in Figure 3.2 and Table 3.1.

3.2 CO_2 Fluxes

Ecosystem respiration (ER) and gross ecosystem productivity (GEP) were highest during the summer months, with GEP displaying a larger seasonal variation (Figure 3.3). Monthly ER values ranged between 6.7 g C-CO_2 m^{-2} (December 2010) and 38 g C-CO_2 m^{-2} (August 2003). Monthly GEP values ranged between 3.2 g C-CO_2 m^{-2} (December 2009) and 63.7 g C-CO_2 m^{-2} (July 2005). On an annual basis, ER was highest during 2007 and GEP during 2005 (Figure 3.3).

The start of the growing season varied between 23 April in 2004 and 27 May in 2010, whereas the end of the growing season ranged between 15 September in 2011 and 5 October in 2005. The start of the growing season is defined as the point in the time

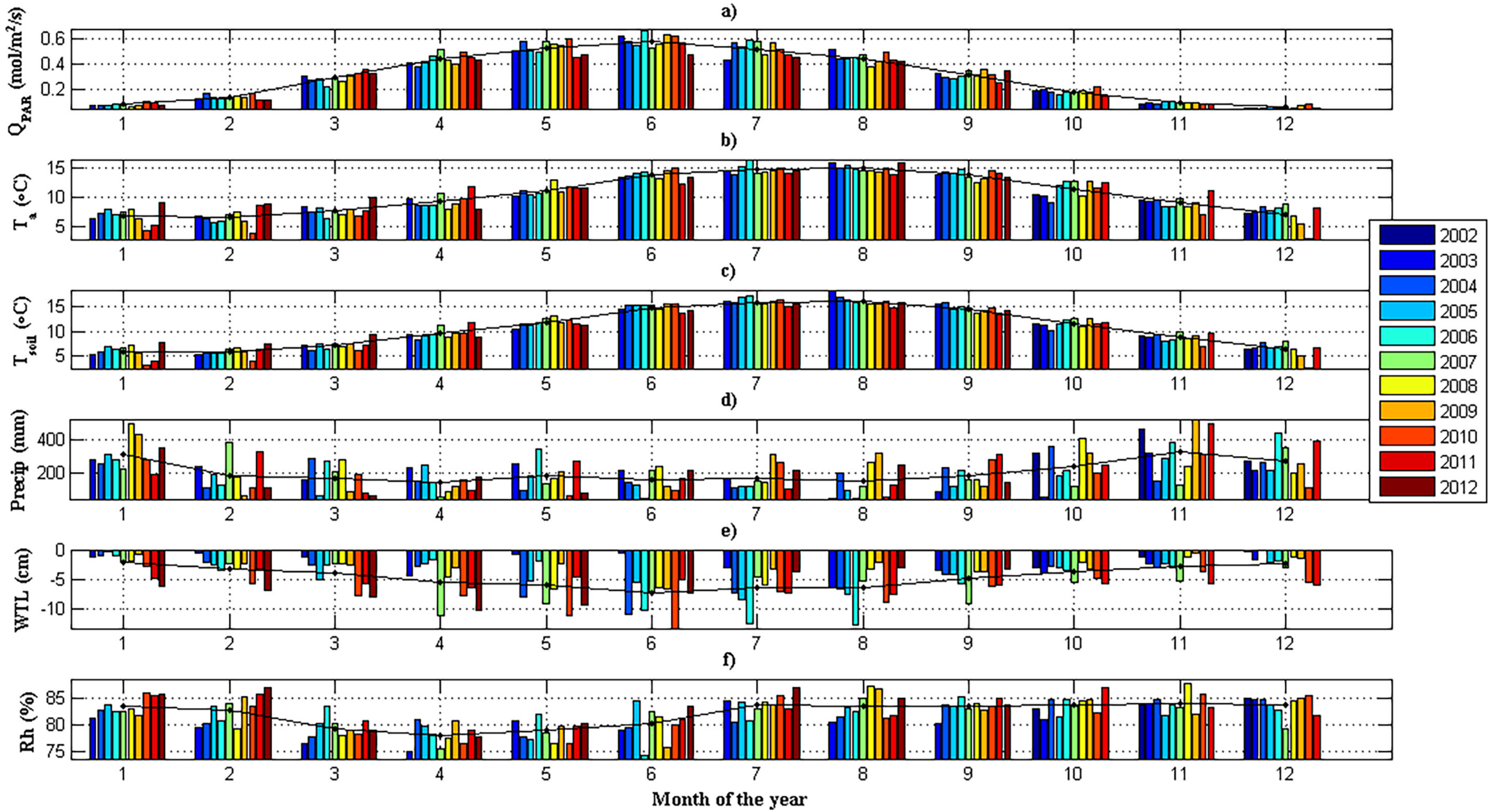

Figure 3.1. Monthly values for meteorological variables across all years. (a) Total Q_{PAR}, (b) average T_{air}, (c) average $T_{soil\ 5cm}$, (d) total precipitation, (e) average WTL and (f) average Rh. The dots joined by black lines represent the average for each month across all years. Reproduced from McVeigh *et al.* (2014) with permission from Elsevier.

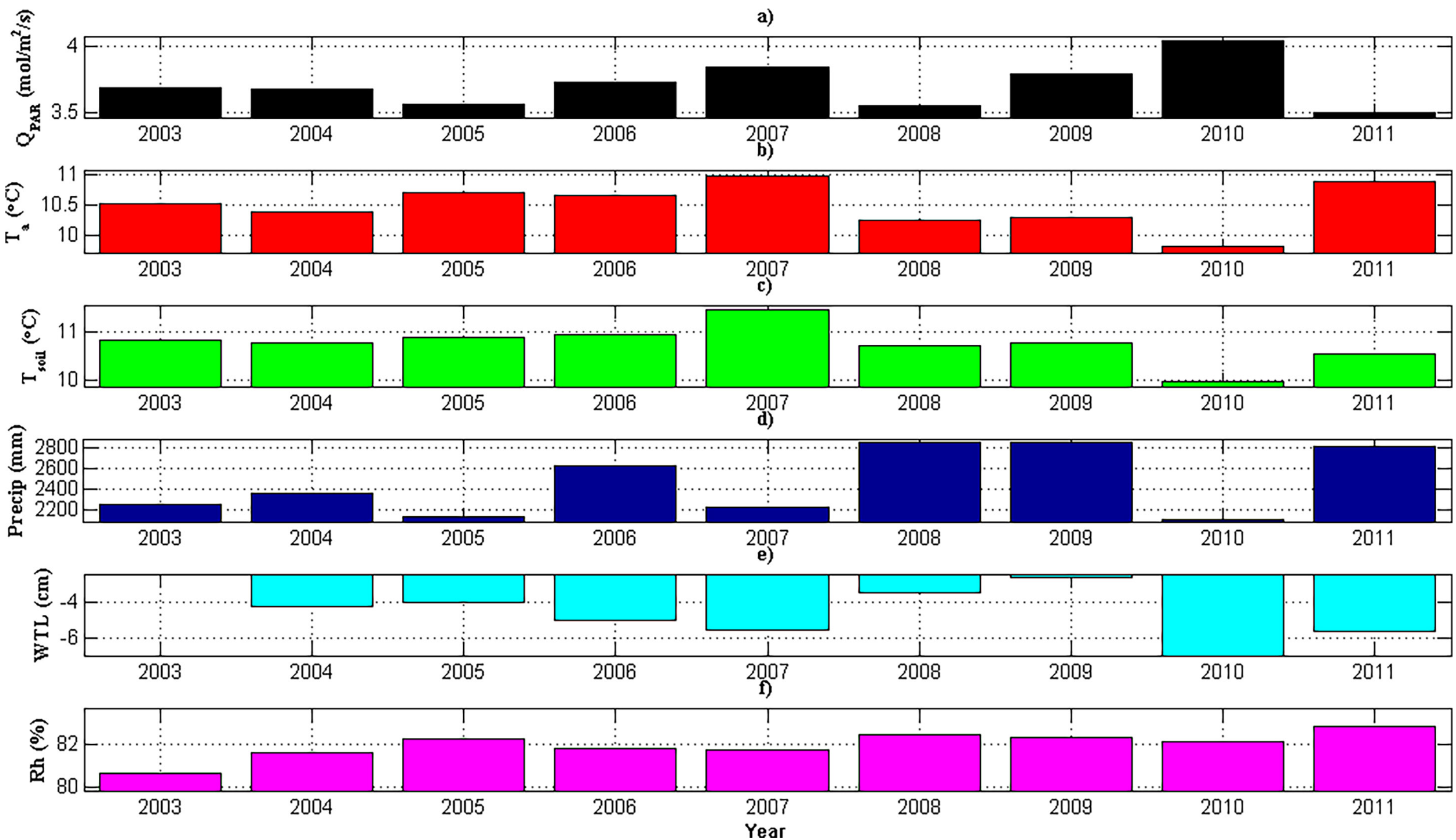

Figure 3.2. Annual values for meteorological variables during each year of measurements. (a) Total Q_{PAR}, (b) average T_{air}, (c) average $T_{soil\,5cm}$, (d) total precipitation, (e) average WTL and (f) average Rh. Reproduced from McVeigh *et al*. (2014) with permission from Elsevier.

Table 3.1. Annual sums or averages (see section 4.1) for each year for various meteorological and CO_2 exchange variables

Variable	2003	2004	2005	2006	2007	2008	2009	2010	2011
Q_{PAR} (μmol^{-1} m^{-2} s^{-1})	3.68	3.67	3.55	3.73	3.84	3.54	3.79	4.04	3.49
T_{air} (°C)	10.51	10.38	10.70	10.66	10.97	10.25	10.30	9.82	10.88
$T_{soil\ 5cm}$ (°C)	10.84	10.77	10.89	10.95	11.46	10.71	10.78	9.97	10.55
Precip (mm)	2254.2	2355.6	2134.9	2617.5	2229.9	2843.1	2854.4	2106.1	2810.5
WTL (cm)	–2.42	–4.20	–4.01	–4.99	–5.50	–3.50	–2.63	–7.01	–5.63
Rh (%)	80.65	81.62	82.25	81.82	81.73	82.41	82.32	82.08	82.84
NEE (g C-CO_2 m^{-2})	–67.9	–75.9	–79.2	–32.3	–32.1	–57.4	–59.3	–42.9	–54.2
ER (g C-CO_2 m^{-2})	236.0	233.6	234.7	236.5	244.8	227.4	231.3	220.8	223.1
GEP (g C-CO_2 m^{-2})	303.8	309.4	313.9	268.8	276.9	284.8	290.6	263.7	277.3

Precip, precipitation.

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series at which there is a change between respiration and uptake in the NEE fluxes.

Cumulative values for NEE, GEP and ER indicate that on an annual basis the Glencar peatland acted as a net (annual) sink of direct CO_2 NEE throughout the entire period of measurements, ranging between an annual NEE of −80 g C-CO_2 m^{-2} in 2005 and −32 g C-CO_2 m^{-2} in 2007, with an overall annual average of −55.7 ± 18.9 g C-CO_2 m^{-2} (Figure 3.4).

3.3 CH_4 Fluxes

CH_4 flux from the peatland differed between microform type (Laine *et al.*, 2007a). This is shown in Table 3.2 and Figure 3.5 where we see that the CH_4 flux decreases with elevation (lowest flux from hummocks, which is the microform of highest elevation) and greatest flux from hollows (lowest elevation). As high lawns make up the greatest percentage (61%) of cover in the EC footprint, they contribute most to the average flux.

Integrating the flux from all microforms according to their spatial distribution within the EC footprint, the annual emission of CH_4 ranged from 3.6 to 4.6 g C-CH_4 m^{-2} yr^{-1} with a 6-year mean of 4.1 ± 0.5 (±1 standard deviation) g C-CH_4 m^{-2} yr^{-1} (Figure 3.6, Table 3.3, Table 3.4). The standard errors of the average annual CH_4 flux varied between years and microforms. The methane flux from hollows including *M. trifoliata* had the highest variation between replicate plots (6-year average ± 2.6 g C-CH_4 m^{-2} yr^{-1}) and hollows with moss cover had the lowest variation (6-year average ± 0.6 g C-CH_4 m^{-2} yr^{-1}). The weighted error across all microforms ranged from 1.6 to 2.0 g C-CH_4 m^{-2} yr^{-1} over the 6 years. On a seasonal basis, the flux increased in the order: winter < spring < autumn < summer, and with increased flux the variation among the 6 years also increased.

In a relative sense, the annual emission flux of CH_4 is of the order of 5 g C-CH_4 m^{-2} yr^{-1} by comparison with an annual sink flux of CO_2 of the order of 50 g C-CO_2 m^{-2} yr^{-1}.

3.4 DOC Fluxes

In Figure 3.7 we show the mean monthly air temperature, the half-hourly streamflow and half-hourly DOC concentration for 2007. The range of DOC concentration is small, ranging from lows of ~4 mg L^{-1} to highs of ~12 mg L^{-1}. The summer concentrations of DOC are about twice the winter DOC concentrations. Increasing streamflow (i.e. during flood periods) elevates the DOC concentration, which returns to lower values after the flood event. No obvious peaks in the concentration of DOC were visible. The average concentration for the month with the lowest concentration, January, and the month with the highest concentration, August, were 3.3 and 8.9 mg L^{-1}, respectively, with an annual average of 6.5 mg L^{-1}.

In Figure 3.6a, we show the monthly stream discharge and the mean monthly DOC concentration. As a result of the regular rainfall pattern, the discharge during May to October 2007 was high, but lower than during the remaining months. About 35% of the annual discharge occurred during the 6-month period from May to October.

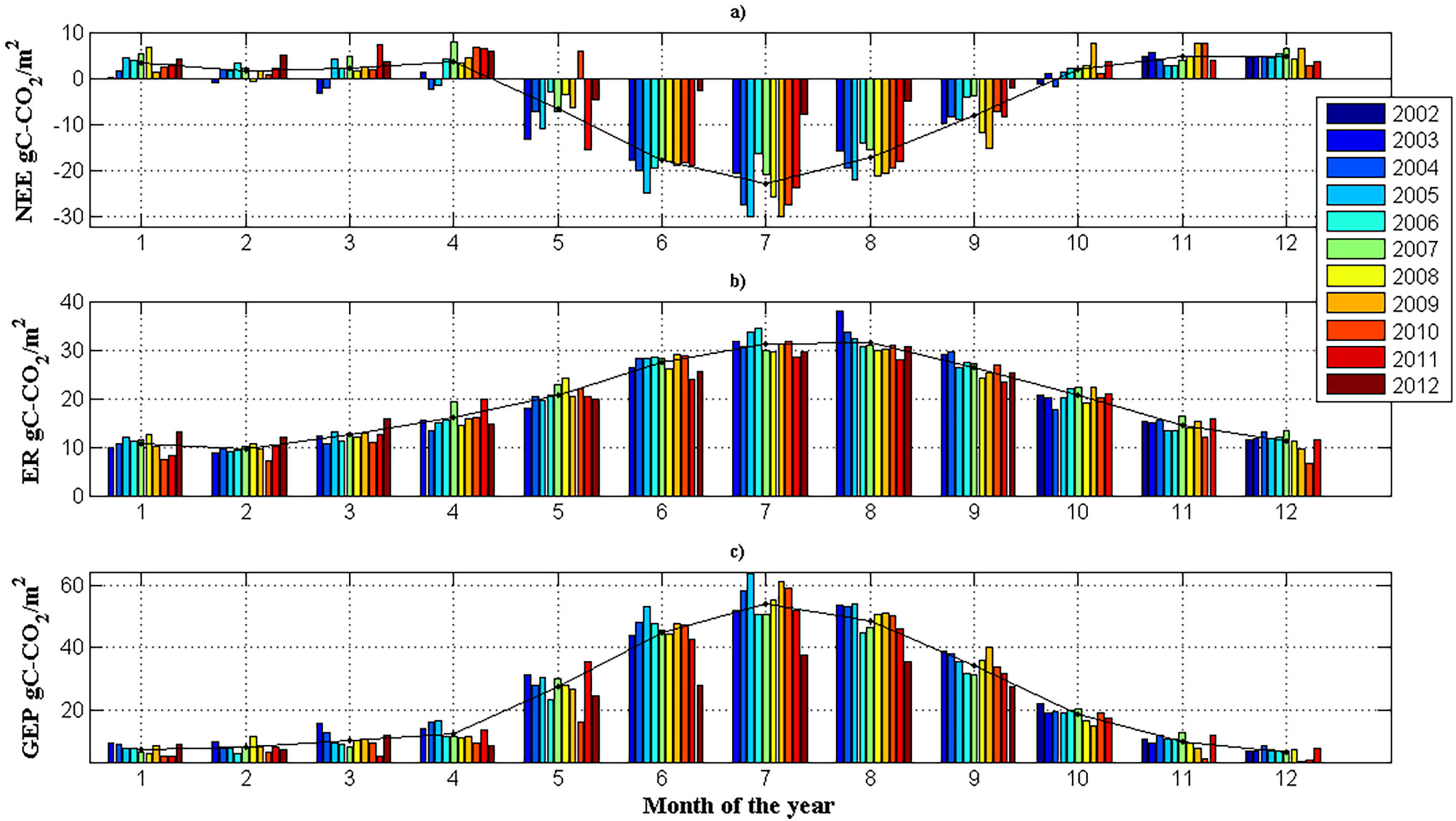

Figure 3.3. Monthly sums of CO_2 flux components across all years. (a) NEE, (b) ER, (c) GEP. The black dots joined by solid lines represent averages for each month across all years (2003–2011). Reproduced from McVeigh *et al*. (2014) with permission from Elsevier.

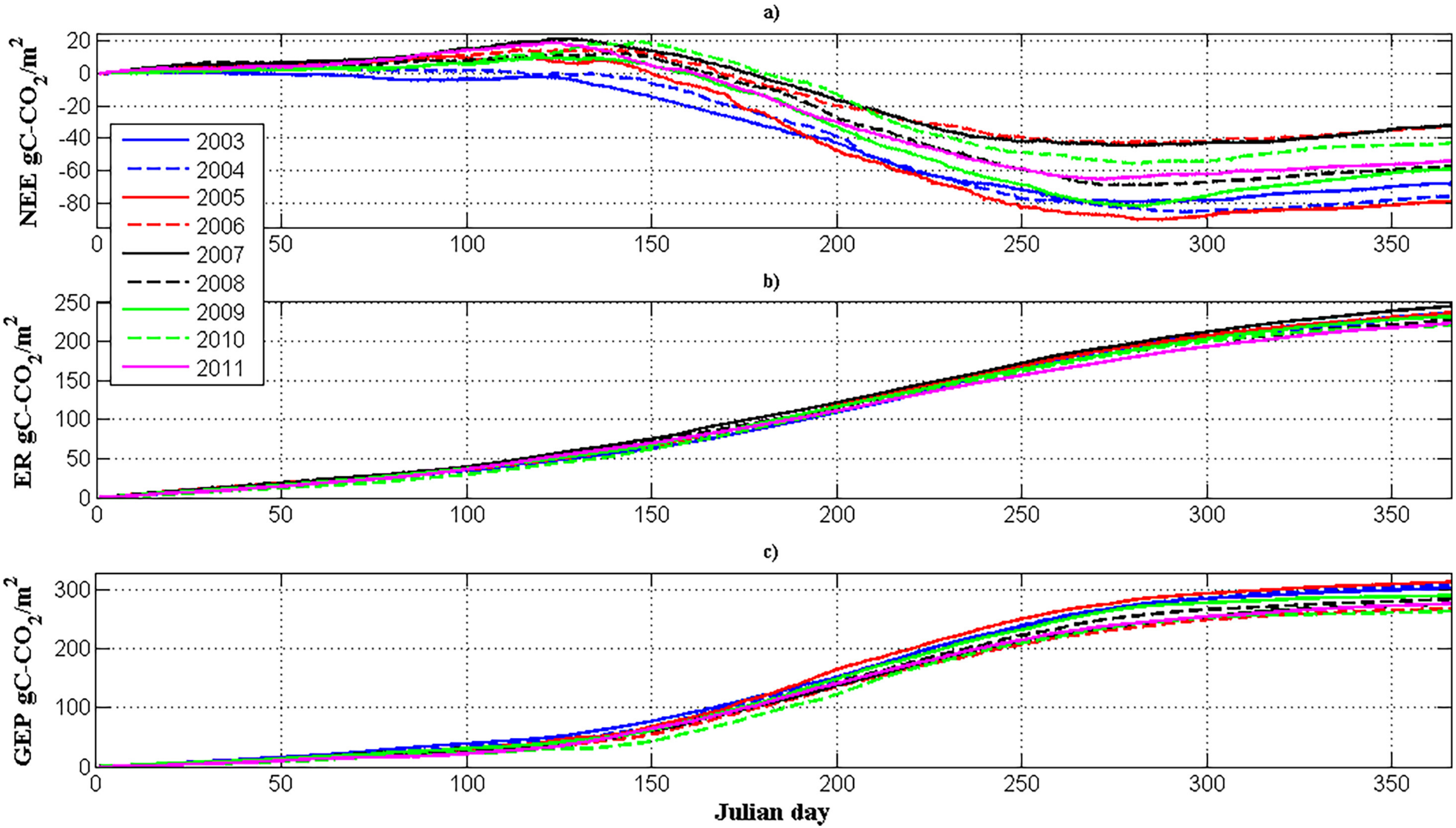

Figure 3.4. Annual cumulative values for each CO_2 flux component. These curves represent consecutive half-hour periods, whereby the values at the end of each curve are equivalent to the annual total values for each component. (a) NEE, (b) ER, (c) GEP. Reproduced from McVeigh *et al*. (2014) with permission from Elsevier.

Table 3.2. CH_4 flux statistics and median water level for vegetation groups: hummock, high lawn, low lawn and hollow

VG	% microform in EC footprint	Annual (g CH_4 m^{-2} yr^{-1})	CH_4 flux (mg m^{-2} day^{-1})					Water level (cm)
			Mean	SD	Min	Max	*N*	Median
HU	6%	3.3 (0.5)	11.8	10.9	0.1	64.1	112	–13
HL	62%	5.8 (1.1)	19.2	19.1	0.0	72.2	109	–5
LL	21%	6.1 (1.4)	20.9	23.3	0.1	101.4	111	–1
HO1	11%	3.5	11.6	9.4	1.7	31.8	23	3
HO2–3		13.0 (0.1)	50.4	54.6	0.3	263.0	50	5

The annual fluxes for HU, HL and LL are calculated for time period 1 October 2003 to 30 September 2004.
Annual fluxes for HO are calculated for time period 1 April 2004 to 31 March 2005.
Standard error of the annual flux is given in parenthesis.
HL, high lawn; HO, hollow; HU, hummock; LL, low lawn; SD, standard deviation; VG, vegetation group.
From Laine *et al*. (2007b).

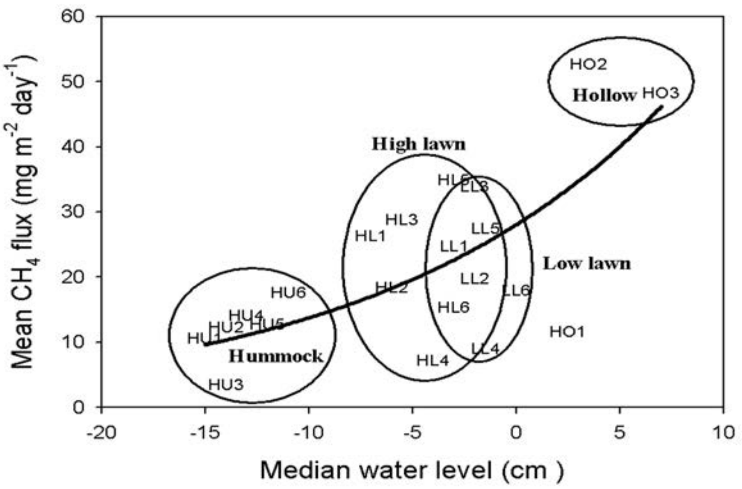

Figure 3.5. Relationship between mean CH_4 flux and median water level of each sample plot. Sample plots are grouped into vegetation groups: hummock, high lawn, low lawn and hollow. From Laine *et al.* (2007b).

The flux of DOC is the product of DOC concentration and streamflow quantity. The measured monthly flux is shown in Figure 3.6b, alongside the modelled monthly flux. The modelled flux is the product of the measured streamflow and modelled DOC concentration (derived from the S-curve relationship shown in Figure 2.3, where we know the air temperature and can therefore model the DOC concentration). The annual flux of DOC for 2007 was calculated to be $14.1 \pm 1.5\,g\,C\,m^{-2}\,yr^{-1}$.

In 2007, about 45% of the DOC flux occurred during storm events corresponding to approximately 10% of the time when the greatest discharge was recorded. Similar results were found in a Canadian wetland (Hinton *et al.*, 1997) and a small upland peat catchment in the northern Pennines, UK (Clark *et al.*, 2007), where 41–57% of DOC was exported during the top 10% of high flows. Given that most DOC was exported during storm events, the likely error of infrequent sampling for the annual DOC flux for Glencar was investigated. Infrequent sampling of once

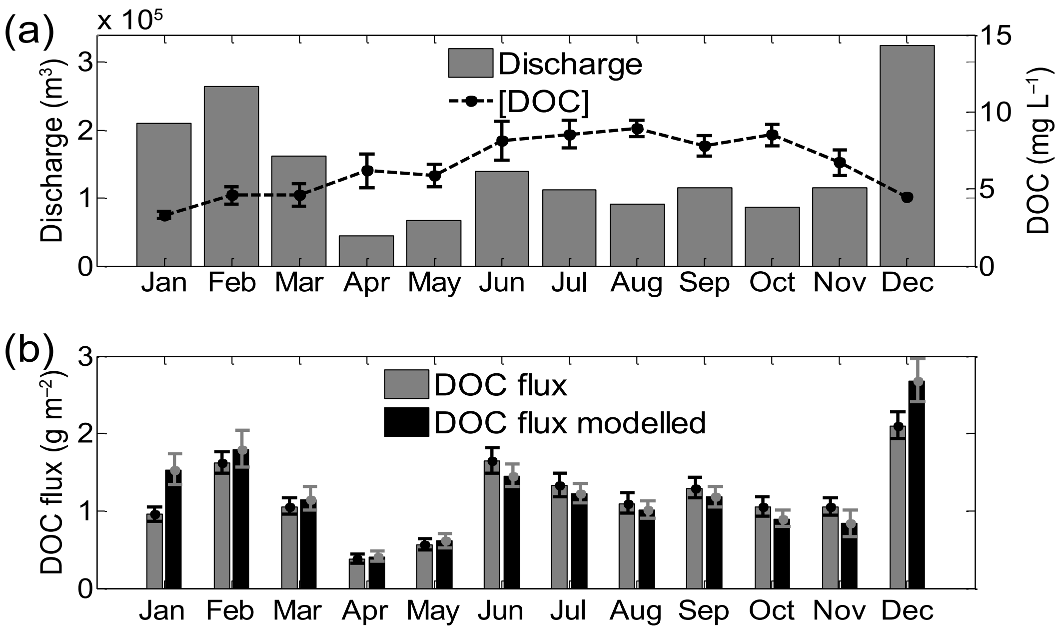

Figure 3.6. (a) Monthly stream water discharge and mean monthly DOC concentration and (b) monthly DOC flux calculated from 30-minute DOC measurements and modelled monthly DOC flux based on the relationship of DOC concentration and T_{air} for 2007. Error bars show the combined error of discharge and drainage basin area for the calculated DOC flux. Modelled DOC flux error bars further include the error given by the 95 % confidence interval on the model as well as the error for the flux calculation (Equation 2.4). Reproduced from Koehler *et al.* (2009) with permission from Springer.

Table 3.3. NEE, CH_4, DOC and carbon balance for Glencar for the years 2003–2008 based on measurements and predictions. The given error estimate for each flux is calculated as described in the materials and methods

Year	NEE g C-CO_2 m^{-2} yr^{-1}	CH_4 g C-CH_4 m^{-2} yr^{-1}	DOC g C m^{-2} yr^{-1}	C balance g C m^{-2} yr^{-1}
2003	–66.8 ± 5.2	3.8 ± 1.6	13.5 ± 3.2	–49.6 ± 6.3
2004	–67.2 ± 3.0	3.6 ± 1.6	13.1 ± 3.1	–50.5 ± 4.6
2005	–84.0 ± 4.8	4.5 ± 1.9	13.9 ± 3.2	–65.6 ± 6.1
2006	–12.5 ± 3.4	4.6 ± 2.0	16.5 ± 3.2	8.6 ± 5.1
2007	–13.5 ± 2.3	4.2 ± 1.9	11.9 ± 1.2	2.8 ± 3.2
2008	–42.7 ± 4.7	3.6 ± 1.6	15.0 ± 1.3	–24.1 ± 5.1
Averages	–48.1	4.1	14.0	–30.0

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a day, once a week and once a month was simulated and this most likely resulted in omitting some of the DOC concentrations during storm discharges. The annual DOC flux estimates for 2007 were 14.1 (±0.1), 14.1 (±0.6) and 14.1 (±1.8) g C m^{-2} yr^{-1} for infrequent sampling of once a day, once a week and once every month, respectively, which compare with 14.1 g C m^{-2} yr^{-1} measured with 30-minute continuous sampling. Therefore, infrequent sampling would result in a similar estimation of the DOC flux to the half-hourly data collection. The more frequently the samples are taken, the lower the standard deviation of the flux, i.e. the chance of getting a flux estimate close to the true value is higher.

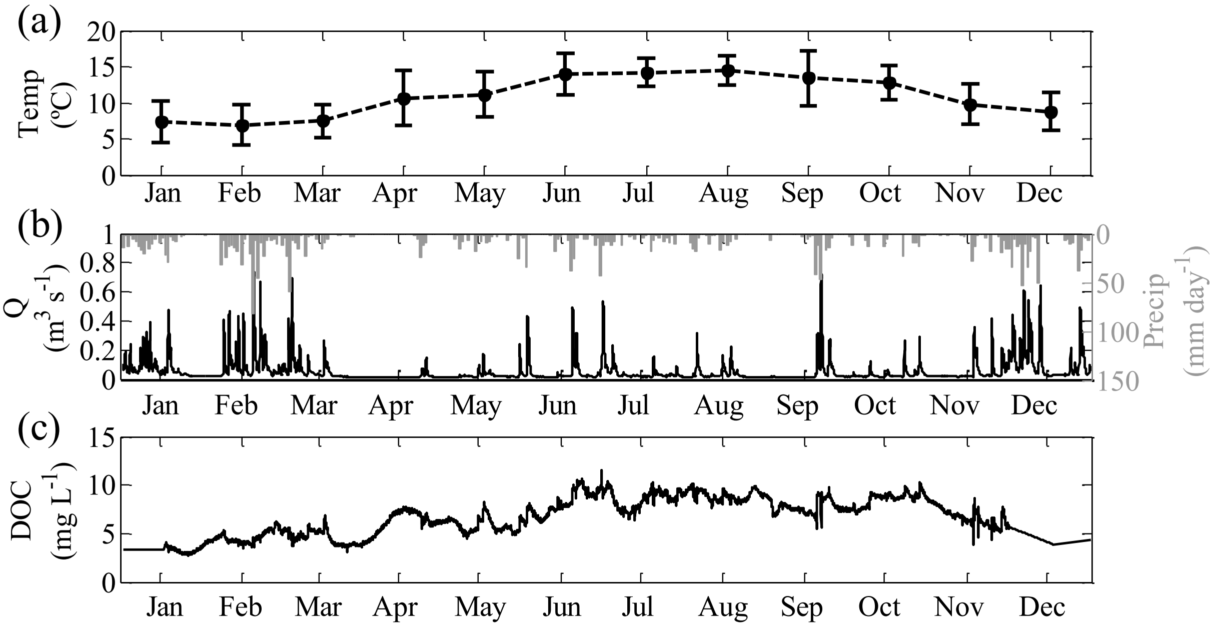

Figure 3.7. (a) Mean monthly air temperature for 2007 including standard deviations, (b) half-hourly streamflow (in black) and daily precipitation (in grey) data during 2007 and (c) half-hourly DOC concentration data. Precip, precipitation; Temp, air temperature. Reproduced from Koehler *et al.* (2009) with permission from Springer.

3.5 Total Carbon Budget

The annual average of the 10 years (2002–2011, Table 3.1) for NEE was −55.7 g C m^{-2} yr^{-1} (McVeigh *et al.*, 2014) and the annual average of the 6 years (2003–2008, Table 3.3) was −48.1 g C m^{-2} yr^{-1} (Koehler *et al.*, 2011). The range of NEE and the annual average is very similar in the two studies. The range of NEE within the 10 years was from a low of −32 g C m^{-2} yr^{-1} (2007) to a high of −80 g C m^{-2} yr^{-1} (2005). The fluxes of CH_4 and DOC are shown in Table 3.3 for the 6-year period 2003–2008. The range of CH_4 fluxes over the 6 years was 3.6–4.6 g C m^{-2} yr^{-1} with an annual average over the 6 years of 4.1 g C m^{-2} yr^{-1}. The range of DOC fluxes over the 6 years was 11.9–16.5 g C m^{-2} yr^{-1}.

When we sum the three component fluxes (CO_2, CH_4 and DOC) over the 6-year period, we get a range of carbon balance of +2.8 to −65.6 g C m^{-2} yr^{-1} with an annual average of −30.0 g C m^{-2} yr^{-1} (Figure 3.8). Combining the annual import and export of carbon for the Glencar bog resulted in a mean 6-year carbon balance of −29.7 ± 30.6 (±1 standard deviation) g m^{-2} yr^{-1}, with NEE being the largest and most variable component of the carbon balance. During the 6 years, NEE was always negative, i.e. a net uptake of CO_2. The calculation of the total carbon balance (C-CO_2 + C-DOC + C-CH_4) showed that the 2 years 2006 and 2007 were small carbon sources whereas the remaining 4 years were sinks for carbon. On average, the carbon loss as CH_4 and DOC accounted for about 9% and 29% of the mean NEE, respectively. Like Roulet *et al.* (2007), we combined all the seasons with the lowest and the highest NEE, CH_4 and DOC to bracket the potential maximum and minimum carbon balance between +15 and −85 g m^{-2} yr^{-1}. This estimation might overestimate the range of the carbon balance.

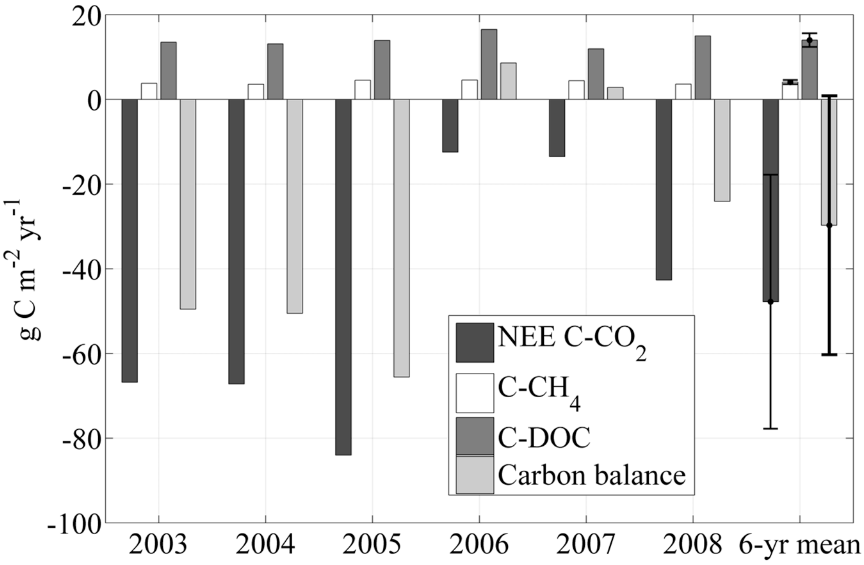

Figure 3.8. Sums of the annual carbon balance components for 2003–2008 and their 6-year mean and standard deviation. The flux of DOC includes only the loss of DOC in the stream. Reproduced from Koehler *et al.* (2011) with permission from John Wiley & Sons, Inc.

4 Discussion

4.1 Meteorology and CO_2 Fluxes

From the meteorological data, precipitation had a high degree of IAV compared with the other variables, with 2009 as the wettest year and 2010 as the driest. The WTL followed a similar, but not identical, pattern to that of precipitation, most likely due to the other factors that can affect it, such as evapotranspiration and surface runoff. Although precipitation levels were high during 2011, a low WTL during 2011 may have been a result of high T_{air} with correspondingly high evapotranspiration.

The start of the growing season occurred between the end of April (2004) and the end of May (2008, 2009 and 2010), whereas the end of the growing season occurred towards the end of September and the beginning of October for all years. This corresponds well with the ecosystem net CO_2 uptake period, highlighted by the inflections in the NEE cumulative curves (Figure 3.4a). The differences in annual NEE are mainly a result of how much growth occurs during the growing season period, which depends on how early it begins and how long it lasts (Figure 3.3a).

The IAV of monthly NEE totals was greatest during May and July, whereas fluxes between November and February were less variable (Figure 3.3). The lower water table years of 2006, 2007, 2010 and 2011 (see Figure 3.1) coincided with the lowest uptake values (see Table 3.1), confirming that ground surface wetness has a significant influence on the IAV of NEE (Sottocornola and Kiely, 2010a,b). This seems to be a result of the correlation between WTL and both GEP and ER. Low WTL in 2006, 2007, 2010 and 2011 is associated with low GEP values, as found in other bog ecosystems with little shrub cover (Sulman *et al.*, 2010), most likely as a result of the important role of the bryophytes in these ecosystems (Sottocornola and Kiely, 2010a,b; Wu *et al.*, 2013). WTL also appears to have a strong negative correlation with NEE_{night}, and therefore ER (see Table 3.1), as found in some other (Bubier *et al.*, 2003b) but not all peatlands (Lafleur *et al.*, 2005; Lund *et al.*, 2010). The connection between WTL and ER is still largely unclear (Frolking *et al.*, 2011), probably because of the dual nature of respiration, both autotrophic and heterotrophic, which responds to different drivers (Yurova *et al.*, 2007). The effect of WTL on NEE is not so obvious in the seasonal data, but it seems that the dry summer of 2006 and spring of 2007 might have affected uptake during the growing seasons of 2007 and 2008 (Figures 3.1 and 3.3), indicating a possible lag effect of dry periods on NEE (van der Molen *et al.*, 2011).

Net emission of CO_2 to the atmosphere (positive NEE values) across all years generally occurred between October and April. The peatland ecosystem behaved as a net sink during the growing season, and throughout all growing seasons and it was only during the very dry month of May 2010 that the bog acted as a net source. These observations are in keeping with the findings of Laine *et al.* (2009).

Over the 10 years of measurements, the average annual uptake of -55.7 ± 18.9 g C-CO_2 m^{-2} for the NEE of atmospheric CO_2 at Glencar was similar to findings at other peatland sites. From 2 years of measurements, the Stordalen palsa mire (a nutrient-poor permafrost peatland) in Sweden was found to be a net sink of carbon, with an average annual uptake of -46 g C-CO_2 m^{-2} per year (Olefeldt *et al.*, 2012). Using 2 years of data, Nilsson *et al.* (2008) found that a boreal minerogenic oligotrophic mire in northern Sweden was also a net annual sink of -55 g C-CO_2 m^{-2}. At the same location, a separate study by Sagerfors *et al.* (2008) found the mire to be an annual net sink of -55 g C-CO_2 m^{-2} following 3 years of continuous EC measurements. The annual NEE average in a northern aapa mire at Kaamanen, Finland, was reported to be -22 g C-CO_2 m^{-2} over a 6-year period (Aurela *et al.*, 2004). Auchencorth Moss, an ombrotrophic peatland with light grazing in southern Scotland, was also found to be a net sink after 2 years of measurements, with an average annual uptake of -69.5 g C-CO_2 m^{-2} (Dinsmore *et al.*, 2010). Mean NEE values calculated by Roulet *et al.* (2007) using a data set of 6 years showed that the Mer Bleue ombrotrophic raised bog in Ontario, Canada, was on average a net annual sink for NEE of -40.2 g C-CO_2 m^{-2}.

4.2 Methane and DOC Fluxes

The flux of CH_4 in Glencar seemed to be more strongly related to temperature than to changes in WTL. The inclusion of the WTL in the non-linear regression model of Koehler *et al*. (2011) increased the explanatory power only for the wettest plots. Hence, the spring, summer and autumn with the highest CH_4 flux corresponded to the years with the warmest temperatures. Winter CH_4 flux showed only a very small IAV because of its very low flux.

In Glencar, the highest monthly DOC flux did not occur at the same time as the highest DOC concentrations in the stream, which occurred during the summer (Koehler *et al.*, 2009). While in Glencar the DOC concentration showed a strong relationship to temperature (Figure 2.3), the DOC flux is controlled by the discharge (Koehler *et al.*, 2009). Therefore, no clear seasonal pattern can be observed for the DOC flux, but the highest flux corresponded to the season with the highest precipitation. Glencar has an annual rainfall of approximately 2500 mm, which is twice that of Cork and three times that of Dublin region. As the flux of DOC is proportional to the streamflow amount, it is clear that there are high exports of DOC from Atlantic blanket bogs, as these are located in the west of Ireland and have an average annual rainfall in excess of 2000 mm.

4.3 Total Carbon Budget

The following discussion of total carbon budget is adapted from Koehler (2012). It was noted that there are only two comparable studies presenting a multi-annual carbon balance of a peatland ecosystem. Roulet *et al.* (2007) examined 6-year carbon balance of the Mer Bleue peatland, an ombrotrophic continental raised bog in south-east Canada, while Nilsson *et al.* (2008) presented 2-year carbon balance from the Degerö Stormyr peatland, a minerogenic oligotrophic mire in northern Sweden. Despite differences in plant functional types, hydrology (runoff of about 400 and 450 mm yr^{-1} for Mer Bleue and Degerö Stormyr, respectively, compared with >1900 mm yr^{-1} in Glencar), the average carbon balance of the three peatlands showed very similar results (Table 4.1). Glencar and Mer Bleue's carbon balance showed a large IAV of similar order ranging from a sink to a source of carbon, while Degerö Stormyr's carbon balance exhibited a low IAV and was a sink in each year of measurement (Table 4.1). In addition, the partitioning of the component fluxes and their IAV was very similar for Glencar and Mer Bleue but somewhat different for Degerö Stormyr (Table 4.1).

For all three sites, NEE was the main component of the carbon balance for most years. The average annual NEEs were very similar, with Glencar and Mer Bleue exhibiting a much larger IAV than Degerö Stormyr (5-year NEE records, Nilsson *et al.*, 2008; Sagerfors *et al.*, 2008). Even though similar on an annual scale, seasonally Glencar and Degerö Stormyr showed a lower carbon loss during the winter and a smaller uptake during the growing season than Mer Bleue. Though there are multiple factors influencing NEE, the lower summer uptake in Glencar might be mainly attributed to a lower LAI than that of Mer Bleue (Glencar: 0.6 $m^2 m^{-2}$, Mer Bleue: 1.3 $m^2 m^{-2}$) while the lower loss in winter in Glencar is probably due to some uptake by mosses and evergreen vascular

Table 4.1. NEE, CH_4 and DOC (total organic carbon for Degerö Stormyr) (±1 standard deviation) for Glencar, Mer Bleue and Degerö Stormyr and their estimated carbon balance including the three fluxes

Variable and unit	Glencar (Ireland)	Mer Bleue (Canada)	Degerö Stormyr (Sweden)
NEE g C-CO_2 m^{-2} yr^{-1}	–47.8 ± 30.0	–40.2 ± 40.5	–51.5 ± 4.9 (5-yrs −53.6 ± 5.6)
CH_4 g C-CH_4 m^{-2} yr^{-1}	4.1 ± 0.5	3.7 ± 0.5	11.5 ± 4.9
DOC (TOC) g C m^{-2} yr^{-1}	14.0 ± 1.6	14.9 ± 3.1	13.0 ± 1.5
C balance g C m^{-2} yr^{-1}	–29.7 ± 30.6	–21.5 ± 39.0	–27.1 ± 7.0

TOC, total organic carbon.

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plants, since winters are mild and often suitable for photosynthesis (Sottocornola and Kiely, 2010a,b). The authors are not aware of LAI measurements for Degerö Stormyr. The importance of LAI was recently indicated in a NEE comparative study including 12 wetland sites across Europe and northern America that found high CO_2 uptake at sites with high LAI (Lund *et al.*, 2009).

The flux and IAV of CH_4 are larger in Degerö Stormyr than in Glencar and Mer Bleue, where they showed similar values (Table 4.1). The low CH_4 flux in Mer Bleue is probably due to the dryness of the site [water table between 20 cm and 70 cm below the surface (Roulet *et al.*, 2007)], compared with Glencar and Degerö Stormyr [water tables about 15 and 20 cm below the surface, respectively (Nilsson *et al.*, 2008)]. Even so, the CH_4 flux in Glencar is surprisingly only slightly higher than in Mer Bleue considering Glencar's high WTL, large proportion of sedges, higher pH (Glencar: 4.5 > Degerö Stormyr: 4 > Mer Bleue: 3.9) and no extreme soil sulfate concentration (0.52–3.81 mg L^{-1}) compared with measurements in other peatlands in Ireland, the UK and Canada (1.9–9.6 mg L^{-1}) (Wind-Mulder *et al.*, 1996; Adamson *et al.*, 2001; Proctor, 2006). These factors favour CH_4 flux. The higher CH_4 flux in Degerö Stormyr than in Glencar might depend on Degerö Stormyr being dominated by lawn and carpet plant communities, microforms that were responsible for the highest efflux in Glencar (see also Laine *et al.*, 2007a). It has to be noted that the technique used for CH_4 measurements might introduce possible bias in the comparison. All three sites used the chamber technique measuring fluxes at the plot scale (covering <1 m^2) and not ecosystem scale, with time intervals being at best weekly and lacking diurnal variations. Furthermore, different annual flux calculation models (Glencar: non-linear regression; Mer Bleue and Degerö Stormyr: linear interpolation) and winter flux estimations were used (based on winter measurements in Glencar and no winter measurement in Mer Bleue, considered 20% of annual flux in Degerö Stormyr). Moreover, the CH_4 flux might be underestimated, as ebullition can occur and this is not well captured by chamber measurements (Christensen *et al.*, 2003).

The annual flux of DOC is similar at the three sites, though examining the combination of concentration and discharge reveals major differences. In Glencar, the mean annual DOC concentration is very low (6.3 mg L^{-1}, with DOC being about 93.5% of total organic carbon) compared with Mer Bleue (47.5 mg L^{-1}) and Degerö Stormyr (total organic carbon concentration of 27.8 mg L^{-1}). The low mean and small absolute range of DOC concentration in Glencar (Koehler *et al.*, 2009) together with the high discharge (>1900 mm yr^{-1}) supports the suggestion that Glencar does not accumulate DOC in the soil because it is continuously flushed by frequent rain events (even in the summer). For Degerö Stormyr and Mer Bleue, a buildup of DOC in the soil is likely to occur during the summer because of extended dry periods, resulting in a flushing of DOC after rain events in late summer and autumn so that storage of DOC varies over the year more considerably than in Glencar. Despite these different patterns, the annual DOC exports are similar for the three sites. In Glencar, frequent heavy rains are accompanied by low DOC concentrations resulting in high DOC flux throughout the year, whereas in Mer Bleue and Degerö Stormyr the DOC concentrations are higher and the discharge lower on an annual basis and the annual carbon export results from episodes with high flow rates, most importantly the spring snowmelt and the late summer and autumn intense rains (Roulet *et al.*, 2007; Nilsson *et al.*, 2008).

For Glencar, the average annual carbon balance for the 6 years was converted into an approximate growth rate of the peatland surface of 1.3 mm yr^{-1} using bulk peat density measurements of 0.045 g cm^{-3}. This value cannot be directly compared with peat core studies of peat accumulation rates such as those over the past 400 years of 0.4 mm yr^{-1} for the Mer Bleue bog (Roulet *et al.*, 2007). Turunen *et al.* (2004) give an average bulk density for 23 Canadian peatlands, including Mer Bleue, of 0.042 and 0.051 g cm^{-3} for hummocks and hollows, respectively, which would convert the average carbon balance of Mer Bleue to a peat height growth of 0.8–1.0 mm yr^{-1}.

In summary, Glencar, Mer Bleue and Degerö Stormyr showed similar average annual carbon balances, with NEE being the main component for most of the years. Despite differences in peatland types, climatic and geographical location, most NEE studies report multiple year averages between 20 and 60 g C m^{-2} yr^{-1} (Limpens *et al.*, 2008) even if single years can vary largely as observed for Glencar and Mer Bleue.
An important factor controlling the rate of carbon sequestration was found to be the peatland surface structure (Belyea and Malmer, 2004). Eppinga *et*

al. (2009a) suggested that different combinations of structural mechanisms (peat accumulation, water ponding and nutrient accumulation) lead to the development of similar peatland surface patterns, which could explain the development of different peatland types into similar stable structures (Eppinga *et al.*, 2009b). It has been argued that these similar structures might then exert a form of top-down control on peatland development in which large-scale features (i.e. peatland size and shape) may constrain processes operating at a smaller scale (such as acrotelm transmissivity or peat formation rate), leading to similar self-regulating processes (Belyea and Baird, 2006). This might offer some explanation of the similar peat accumulation rates in different peatland types observed for Glencar, Mer Bleue and Degerö Stormyr.

5 Conclusions and Recommendations

5.1 Conclusions

The Glencar pristine blanket peatland:

- is a sink for CO_2 of the order of $-50\,g\,C\text{-}CO_2\,m^{-2}\,yr^{-1}$;
- is a source of DOC of the order of $+14\,g\,C\text{-}DOC\,m^{-2}\,yr^{-1}$;
- is a source of CH_4 of the order of $+4\,g\,C\text{-}CH_4\,m^{-2}\,yr^{-1}$;
- has a total carbon sink balance of the order of $-30\,g\,C\,m^{-2}\,yr^{-1}$.

The IAV in NEE ranges from −31 to $-78\,g\,C\text{-}CO_2\,m^{-2}\,yr^{-1}$, which is a "sink" that is approximately one-fifth the size of that in Irish grasslands and less than one-tenth that of forests in Ireland.

In this report we present the results of a multi-annual carbon balance study of the Glencar Atlantic blanket bog in County Kerry, south-west Ireland. We show that NEE is not the only important component of the peatland carbon balance but that the CH_4 flux and stream water DOC flux are also crucial components. NEE accounts for about 73% of the average annual carbon balance, while the CH_4 flux and streamwater DOC flux contribute about 6% and 21%, respectively. However, for 2 of the 6 years, the sum of the CH_4 and DOC flux exceeded the NEE, making the site a source of carbon for the years 2006 and 2007. NEE had a significant IAV, while both the CH_4 flux and stream water DOC flux showed low IAV. Therefore, the annual behaviour of NEE is the most important component determining the bog's annual carbon status. The existence of similar self-regulating processes in peatlands was suggested in the literature to be a possible mechanism leading to similar peat accumulation rates in different peatland types as observed for Glencar, Mer Bleue and Degerö Stormyr.

For further investigation of these processes and an understanding of the impact of the climate change on peatland ecosystems, continuation of the current carbon balance studies and extension of the measurements of the total carbon balance to other peatland sites are important.

5.2 Recommendations

1. The Glencar site is a unique pristine blanket peatland and is one of only three long-term study sites in the world of which the authors are aware. Given this, it is desirable to continue maintaining this research site lest the instrumentation fall into disrepair and Ireland lose the human capability to continue research at this site.
2. Glencar should be instrumented with a CH_4 gas analyser for EC measurements of CH_4 flux. Chamber studies are expensive in labour cost and there is a risk that chambers may miss significant events such as night-time pulses of CH_4.
3. The instrumentation at Glencar was first installed in 2002 and is now showing its age and wear. It is recommended that the instrumentation be upgraded in line with ICOS standards of instrumentation for long-term international GHG flux sites.
4. Modelling work should be developed as part of ongoing research at this site.
5. Remote sensing expertise is urgently required to extend the results of GHG fluxes from the EC scale of ~1 km^2 so that upscaling to the regional (~1000 km^2) and national scale fluxes from peatlands can be developed.

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Abbreviations

BP	Before present
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
DOC	Dissolved organic carbon
EC	Eddy covariance
ER	Ecosystem respiration
G	Soil heat flux
GEP	Gross ecosystem production
GHG	Greenhouse gas
H	Sensible heat fluxes
IAV	Interannual variation
ICOS	Integrated Carbon Observation System
LAI	Leaf area index
LE	Latent heat fluxes
m asl	Metres above sea level
NEE	Net ecosystem exchange
P_a	Atmospheric pressure
POC	Particulate organic carbon
Q	Discharge
Q_{PAR}	Photosynthetic active radiation
Rh	Relative humidity
Rn	Net solar radiation
SOC	Soil organic carbon
T_{air}	Air temperature
$T_{soil\ 5cm}$	5-cm depth soil temperature
WD	Wind direction
WS	Wind speed
WTL	Water table level
x_f	Fetch length

Appendix 1

Recent UCC PhD Thesis Titles Funded by the EPA on Peatland Fluxes

Anna Laine – (2006): Carbon Gas Fluxes in an Irish Lowland Blanket Bog

Matteo Sottocornola – (2007): Four Years of Observations of Carbon Dioxide Fluxes, Water and Energy Budgets, and Vegetation Patterns in an Irish Atlantic Blanket Bog

Ciaran Lewis – (2013): Measurement and Modelling of Soil Hydrological Properties for Use in the Distributed Rainfall Runoff Model – GEOtop

Key Papers based on Glencar Research on Peatland Fluxes

Petrescu, A.M.R., Lohila, A., Tuovinen, J.-P., Baldocchi, D.D., Desai, A.R., Roulet, N.T., Vesala, T., Dolman, A.J., Oechel, W.C., Marcolla, B., Friborg, T., Rinne, J., Matthes, J.H., Merbold, L., Meijide, A., **Kiely, G.**, Sottocornola, M., Sachs, T., Zona, D., Varlagin, A., Lai, D.Y., Veenendaal, E., Parmentier, F.J., Skiba, U., Lund, M., Hensen, A., van Huissteden, J., Flanagan, L.B., Shurpali, N.J., Grünwald, T., Humphreys, E.R., Jackowicz-Korczyński, M., Aurela, M.A., Laurila, T., Grüning, C., Corradi, C.A., Schrier-Uijl, A.P., Christensen, T.R., Tamstorf, M.P., Mastepanov, M., Martikainen, P.J., Verma, S.B., Bernhofer, C., Cescatti, A. (2015). The uncertain climate footprint of wetlands under human pressure. *Proceedings of the National Academy of Sciences of the United States of America* 112(15): 4594–4599. Published: 14 April 2015.

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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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PeatGHG - Survey of GHG Emission and Sink Potential of Blanket Peatlands

Authors: Gerard Kiely, Paul Leahy, Philip McVeigh, Ciaran Lewis, Matteo Sottocornola, Anna Laine and Ann-Kristin Koehler

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

Identifying Pressures

Pristine peatlands are mostly sinks for carbon, while harvested or cut-away peatlands are sources of carbon. The principal pressures on Irish peatlands are associated with anthropogenic activities over the past few hundred years, namely:

- exploiting peat for fuel, electricity generation and horticulture use,
- draining peatlands for agricultural, upland grazing and afforestation use,
- risks from climate change (e.g. rising temperatures).

Such activities have lowered the water table and cut away peat depth to several metres in places, leaving exposed peat and non-vegetative land surfaces. In the coming decade, these activities will decrease due to the end of Bord na Móna's use of peat for electricity generation. However, this will leave extensive areas with degraded peat surfaces. The key challenge now is how to manage these degraded peatlands sustainably (in a carbon-neutral way) and to preserve the remaining pristine peatlands in the face of the continued pressure from anthropogenic climate change.

Informing Policy

This project has quantified that a near-pristine blanket peatland in Glencar, County Kerry is a net sink for carbon for most years of the decade long field experiment. On the other hand, based on literature reviews, degraded or cut-away peatlands are net sources of carbon emissions. This suggests that the remaining pristine peatlands in Ireland should be conserved as carbon sinks, while degraded peatlands need to be examined further to identify sustainable management strategies into the future.

Developing Solutions

Suggested solutions include conserving the remaining pristine and near-pristine peatlands and protecting peatland margins to maintain hydrological integrity. This will enable this land cover to remain as a sink for carbon into the future. Although it is expected that this sink may reduce under climate change. Management options at cut-away and degraded peatlands need to be examined to minimise carbon losses. Possible management strategies include allowing the water table to be raised to encourage the revegetation or to allow its natural colonisation with tree species such as birch. This is occurring in several areas across Ireland. However, the carbon sink strength of such "new land cover" remains to be determined.

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