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CELTICFLUX: Measurement and Modelling of Greenhouse Gas Fluxes from Grasslands and a Peatland in Ireland

STRIVE

Environmental Protection Agency Programme

2007-2013

Teagasc
Agriculture and Food Development Authority

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

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EPA STRIVE Programme 2007-2013

CELTICFLUX:
Measurement and Modelling of Greenhouse Gas Fluxes from Grasslands and a Peatland in Ireland

(2001-CD-C2-M1)

STRIVE Report

End of Project Report available for download on http://erc.epa.ie/safer/reports

Prepared for the Environmental Protection Agency

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Executive Summary

Internationally, the carbon cycles in forests have been studied more extensively than those in grasslands or peatlands. The magnitude of the CO_2 sink for forests in temperate humid climates has been found to range from ~-5 to -15 tC-CO_2 ha^{-1} yr^{-1} (negative sign indicates a sink). By comparison with forests, grasslands and peatlands in temperate climates have been reported to be either small sinks or small sources for CO_2 of order 0.5 to 2 tC-CO_2 ha^{-1} yr^{-1}, respectively. Table 1 gives the findings of the annual CO_2 fluxes for three Irish sites that have been monitored over the period 2002 to 2008.

For each of the five years of the study, the three sites were sinks for CO_2. The peatland was a small sink for CO_2 (annual average of -0.6 tC ha^{-1} yr^{-1}) while the two grasslands (Dripsey and Wexford) were sinks for CO_2 (of annual average -2.6 tC ha^{-1} yr^{-1} and -4.8 tC ha^{-1} yr^{-1} respectively). The Wexford grassland had a land cover of 100% grassland from 2002 to 2005 (inclusive) and for 2006 and 2007 had a mixed land cover (part grassland and part winter kale). The later land cover resulted in a significant reduction in the size of the CO_2 sink (to -1.75 tC ha^{-1} yr^{-1}). The wet, impeded drainage gley soils at Dripsey are a robust sink for CO_2 even under a wide interannual variability in rainfall. The free-draining soils in Wexford were also a significant sink for CO_2. Under climate change, wetter winters are unlikely to reduce the CO_2 uptake, but warmer summers and an earlier start of the growing season coupled with a longer growing season may enhance the annual CO_2 sink. The N_2O emissions at the Dripsey grassland ranged from +1.6 to +8.6 kg N-N_2O ha^{-1} yr^{-1} corresponding to 1.4% to 4.2% of the nitrogen in the applied artificial fertiliser. The N_2O emissions in global warming potential (GWP) have the effect of reducing the CO_2 uptake by ~20%. The emissions of CH_4 at the peatland were ~0.05 tC-CH_4 ha^{-1} yr^{-1} (or ~10% of the annual C-CO_2 sink).

The small annual sink of CO_2 and high inter-annual variability at the Atlantic blanket peatland suggests that under climate change predictions, blanket peatlands are likely to become sources rather than remain as sinks for CO_2. The huge store of carbon in Irish peatlands is in danger of being lost to the atmosphere under predicted climate change.

To increase the CO_2 uptake and reduce the N_2O emissions from Irish grasslands, alternative grassland management practices to widespread nitrogen fertilisation and silage making should be examined, including: the reduction of N (in fertilisers and slurry); wider use of less intensive grassland management practices, such as the rural environmental protection scheme (REPS); wider use of clover grasses (as an N fixer); and later first cut silage to extend the growing season length and enhance the CO_2 sink.

Table 1: Measured CO_2 fluxes [tC ha^{-1} yr^{-1}] at the three sites in Southern Ireland.

Site name	Ecosystem	Period	CO_2 fluxes
Glencar, Co. Kerry	Blanket peatland	2002–2007	-0.2 to -0.9
Dripsey, Co.Cork	Grassland	2002–2007	-2.1 to -3.9
Wexford	Grassland	2003–2005	-4.2 to -5.8
Wexford	Grassland + kale	2006–2007	-1.3 to -2.2

1. Introduction

1.1 Background

As a signatory to the United Nations Convention on Climate Change (UNFCCC), Ireland is obliged to produce inventories of greenhouse gases (GHGs) (CO_2, N_2O and CH_4) emissions and sinks. Under the Kyoto Protocol, Ireland has committed to limiting the increase in GHGs to 13% above its 1990 levels, a limit set for the period 2008–2012. Agriculture in Ireland is estimated to be the largest contributor to GHG emissions at 26.1% of total (EPA, NIR 2008). There is a small negative trend in agricultural emissions since 1999, owing to decreasing cattle and sheep populations (reducing CH_4 emissions) and decreasing fertiliser use (reducing N_2O emissions) (EPA, NIR 2008). Because of the significance of grasslands to Irish land cover, the economy, GHG emissions, and ongoing land-use changes, the status of grasslands as a source or sink for GHGs needs to be quantified. Grasslands remove CO_2 from the atmosphere via photosynthesis and emit CO_2 to the atmosphere via respiration. When summed over the year, the net effect of photosynthesis and respiration may result in the grassland being either a source or sink for CO_2. Emissions of N_2O are a significant GHG (~298 times more potent than CO_2 at the 100 year timescale) and are released into the atmosphere from grasslands after the application of nitrogen in fertilisers, animal excreta and manures. As for CH_4, O'Mara et al. (2007) have reported on this GHG from ruminant animals. It is generally thought that relatively intact peatlands in Ireland are sinks for carbon. Few field measurements of GHGs have been made in Irish peatlands and so their ecosystem status as a sink or source for carbon has not yet been quantified. Because of their extent in Ireland, covering approximately 17% of the landscape, it is important to determine whether peatlands are a sink or source for GHGs.

1.2 Literature Review

Rising concentrations of GHGs in the atmosphere are contributing to climate change through increased radiative forcing (IPCC, 2007). As of 2007, the concentration of CO_2 in the atmosphere is 379 ppm and of that N_2O is 319 ppb and these are estimated to be increasing by 1.9 ppm and 1.6 ppb per annum respectively since 1998 (IPCC, 2007). In addition, the atmospheric concentration of CH_4 was 1774 ppb in 2005 and increased by 0.7 ppb per annum since 1998 (IPCC, 2007).

1.2.1 Grassland CO_2 Fluxes

Studies of the carbon fluxes in temperate grassland have been overlooked due to the perception that this ecosystem is carbon neutral (Ham & Knapp, 1998). Representing approximately 32% of the earth's natural vegetation, temperate grasslands are now being revisited for carbon flux studies (Frank & Dugas, 2001; Hsieh et al., 2005). Temperate grasslands are the dominant ecosystem in Ireland, representing ~90% of agricultural land (or 54% of the total land area) (Eaton et al., 2008). The necessity of finding economical GHG mitigation strategies is a strong motivation for studying the effects of grassland management on GHG fluxes (Groffman et al., 2000). Several short-term studies have shown that grassland ecosystems can sequester atmospheric CO_2 (Conant et al., 2001) but few multi-annual data sets are available (Novick et al., 2004). Long-term measurements are essential for examining the seasonal and interannual variability of C fluxes (Baldocchi, 2003). Grassland ecosystems may act as either sources or sinks of CO_2. Whether grassland is a source or sink for CO_2 is dependent on the climate, land use and management practices, such as rates of nitrogen fertiliser application. The international literature shows that the net ecosystem exchange of grasslands varies from an uptake of -800 g C m^{-2} y^{-1} to an emission of +521 g C m^{-2} y^{-1} with most grassland ecosystems in the range ±200 g C m^{-2} y^{-1} (Novick et al., 2004).

1.2.2 Grassland non-CO_2 Greenhouse Gas Fluxes

CO_2 flux measurements alone do not give a complete picture of an ecosystem's contribution to radiative forcing. N_2O fluxes, although less widely measured, may be an important contributor to the overall radiative forcing from managed grasslands, especially if significant use is made of nitrogen fertilisers. A preliminary estimate suggests that intensively managed grasslands may receive nitrogen fertilisation in the range of 30 to 60 g N m^{-2} per year. Applying a typical emission factor of 2.2% (Dobbie et al., 1999) this would lead to the emission of 0.66 to 1.32 g N_2O-N m^{-2}, equivalent to a CO_2 emission range of 300 to 600 g m^{-2} yr^{-1}. N_2O with a GWP of 298 (100-year time horizon, IPCC, 2007) has a much stronger radiative forcing effect per unit mass on the atmosphere than CO_2. Therefore, relatively small emissions of N_2O can exert a strong influence on the total radiative forcing budget of an ecosystem. Soil management practices accounted for almost half of anthropogenic N_2O emissions from the agricultural sector in Ireland. There are few long-term studies of grassland N_2O emissions and most of these are based upon chamber measurements (e.g. Dobbie et al., 1999; Hyde et al., 2006; Smith & Dobbie, 2001). With the advent of tunable diode laser (TDL) trace gas analyser systems (Edwards et al., 2003), eddy covariance (EC) measurements of N_2O fluxes have become possible (Laville et al., 1999).

1.2.3 Global Warming Potential

Global warming potential (GWP) is a measure of the relative radiative forcing effect of GHG emissions on the atmosphere (IPCC, 2001). GWP allow the effects of different GHGs to be compared by conversion to an equivalent mass of CO_2 as a reference gas. GWPs from the IPCC's Second Assessment Report based on 100-year time horizons were used: a GWP for N_2O of 298 and for CH_4 of 25 (IPCC, 2007). The combined radiative forcing effect of emissions or uptakes of different gases can be expressed through the concept of net greenhouse gas exchange (NGE), which is the sum of individual GHG fluxes, weighted by their respective GWP.

1.2.4 Peatland CO_2 Fluxes

Although boreal peatlands are generally of low productivity, they are important ecosystems because they contain up to one-third (455 Gt) of the world's estimated soil carbon (C) pool. The future of this C reservoir is of key interest as many regions (e.g. the arctic tundra) have already undergone a C status change from sink to source due to global warming. Climate warming is expected in peatlands to affect the hydrology, the vegetation zones and plant composition (Jones et al., 2006; Weltzin et al., 2003), all factors influencing the C dynamics. Some peatlands have been found to be net sources of CO_2 (Lafleur et al., 1997; Schreader et al., 1998), others were found to be net CO_2 sinks (Aurela et al., 2004; Friborg et al., 2003; Lafleur et al., 2003; Suyker et al., 1997), while others were found to be a sink in one year or a source in another year (Arneth et al., 2002; Joiner et al., 1999). Blanket bogs are ombrotrophic mires receiving water and nutrients only from atmospheric depositions (Hammond, 1981). In the global context, blanket mires are rare ecosystems, accounting only for ~3% of the world peatland surface (Foss et al., 2001). However, locally they are important, not only for biodiversity but for their role in the C balance of regions. In Ireland, out of 1.34 million of hectares covered by peatlands (~17% of the national landscape), about 240,000 ha are blanket bogs (Hammond, 1981). The role of this regionally large ecosystem in C dynamics has not been quantified. Peatlands have a key role in controlling the terrestrial carbon cycle, with a dual effect on atmospheric C gas concentrations (CO_2 and CH_4). Peatlands act as a long-term sink of C, owing to the CO_2 uptake in photosynthesis and incomplete decomposition of the organic matter in water-logged, cold and acidic conditions (Moore & Bellamy, 1974). The residual organic matter, peat, has a high soil organic carbon content of about 50%. The long-term average annual C accumulation rate in different boreal peatlands has ranged from 17 to 29 g m^{-2} (Clymo et al., 1998; Gorham, 1991; Laine et al., 1996).

Global warming potential can be used to compare the climate impacts of different GHGs on peatlands (IPCC, 2001). The GWP of CH_4 is 21 for a 100-year time horizon. Due to the CH_4 emissions, the GWP of peatlands is positive (i.e. warming) over a short time horizon (less than 100 yr) but over longer time horizons the NGE of peatlands can become negative (i.e. cooling). Peatlands are an important natural source of CH_4 (Huttunen et al., 2003; Lelieved et al., 1998), contributing 20 to 30% of the total global CH_4 emissions (IPCC, 2001).

1.3 Aims and Objectives

The objectives of the EPA funded project were as follows:

1 Establish a research capability of measurement and modelling of GHG fluxes for Irish grasslands and peatlands by:

- training scientific personnel in the methods and science of GHG fluxes
- establishing new eddy covariance (EC) towers for measurements of fluxes of CO_2:
  - at the intensively managed grassland site in Dripsey, Co. Cork
  - at the grassland site at Teagasc, Johnstown Castle, Co. Wexford
  - at the intact blanket peatland site at Glencar, Co. Kerry
- set up a TDLA for EC N_2O fluxes at the Dripsey grassland site in Co. Cork
- establish ground-based chamber measurements of CH_4 at the Kerry peatland site.

2 Quantify the CO_2 source/sink status of the three sites.

3 Model the CO_2 and N_2O fluxes at the Cork grassland using PaSim and DNDC.

4 Have a network of field experimental set-ups that will be usable long term and capable of continuity after the five-year project and that can integrate with Met Eireann's network for meteorological data.

2. Materials and Methods

2.1 Experimental Sites

Three sites were selected for GHG flux measurements between 2002 and 2007. These are: the Dripsey grassland, the Wexford grassland and the Kerry peatland, with locations shown in Figure 2.1. Figure 2.2 is a photograph of the Dripsey grassland site with the eddy covariance (EC) tower in the background. Figure 2.3 illustrates the footprint of the EC tower for the Dripsey site. Further details can be found in the End of Project report (available on the EPA website at: http://erc.epa.ie/safer/reports).

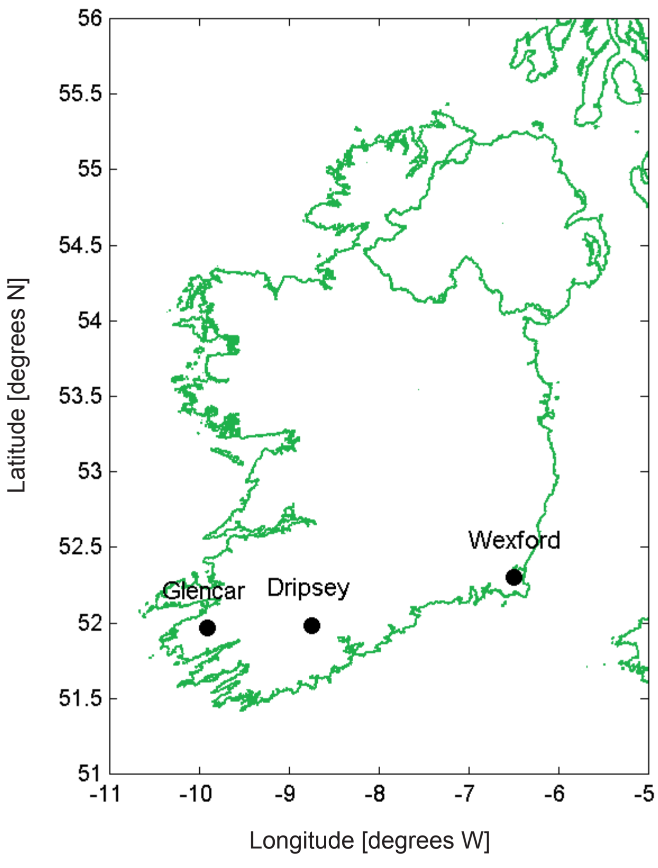

Figure 2.1: Geographic location of three EC flux towers in southern Ireland. Dripsey in Co. Cork is an intensively managed grassland (impeded drainage type soils) at 190 metres above sea level. Wexford is also intensively managed grassland (free-draining soils) with some arable fractions of land cover located at 58 metres above sea level. Glencar is an intact Atlantic blanket peatland in Co. Kerry at 150 metres above sea level.

Figure 2.2: EC tall tower (10 m high) at Dripsey grassland, Co. Cork. Ecosystem is grassland and soils are impeded drainage. EC instruments were set at 10 m for 2002, 2003 and 2004 with associated average footprint extent of 1000 m in south-west direction. For 2005, 2006 and 2007 EC instruments were set at 6 m with associated average footprint extent of 600 m.

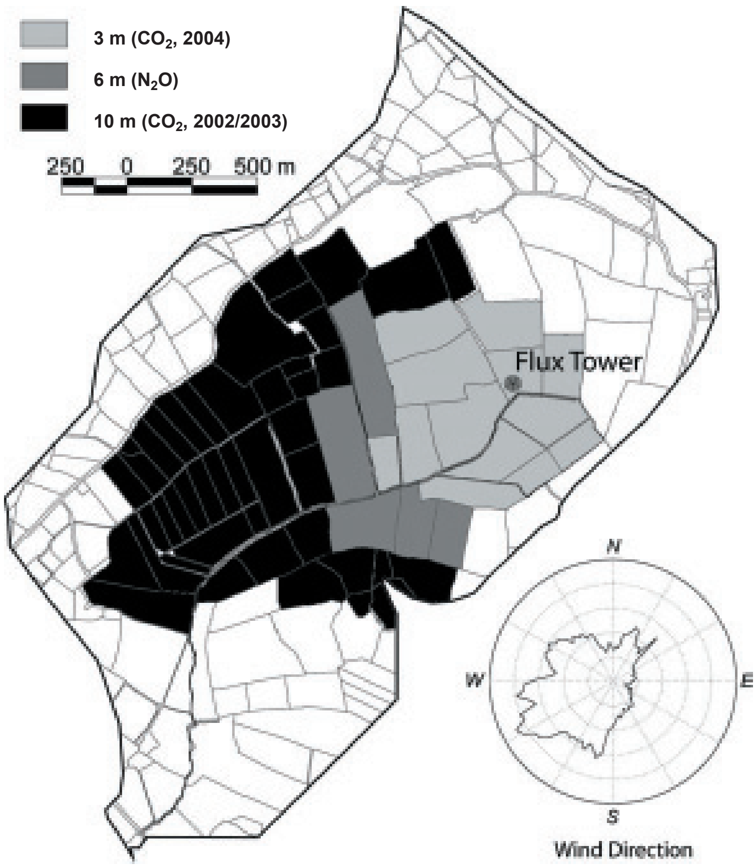

Figure 2.3: Map of Dripsey grassland catchment with EC tower location and shaded fields indicative of the flux footprint depending on height of sensors. Full catchment shown above has an area of 202 ha and includes eight farms. EC footprint has many small fields, varying in size from 1 to 5 ha, separated by 1 m high stone and sod ditches or timber post and wire fences. Prevailing wind direction is from the south-west (inset). When EC instruments (sonic anemometer and Licor 7500) were installed at a tower height of 3 m, footprint extent in the south-west direction was ~300 m.

2.2 Meteorological Methods

Meteorological variables were continuously measured at the three EC tower sites in the south of Ireland. The meteorological data supported the GHG flux measurements as they were used to model missing flux data and used in the process-based models, PaSim and DNDC. Moreover, meteorological variables were used to establish a continuous time series of gas fluxes from intermittent point measurements performed with the chamber technique. Signals from all sensors were averaged (or, in the case of precipitation, summed) over a 30-minute period.

2.3 Eddy Covariance Methods

The eddy covariance (EC) method is a micrometeorological technique that measures the turbulent flux across the vegetation canopy-atmosphere layer to determine the net difference of material moving across this interface (Baldocchi, 2003; Lenschow, 1995). Two fast-response instruments are necessary for EC measurements: a 3-D sonic anemometer and a gas analyser, both operating at high frequency, to cover the full range of the turbulent motion. CO_2 concentrations were measured with an open-path infrared gas analyser (IRGA), installed beside the sonic anemometer. The N_2O concentrations were measured with a closed-path trace gas analyser (TGA). This system consisted of a sensor intake, positioned beside the sonic anemometer, a tube that carries the sample air to the gas analyser which is a tunable diode laser absorption spectrometer tuned for N_2O. (For further details on the EC system refer to the End of Project Report). An averaging time of 30 minutes was chosen, as is globally applied in EC studies. The EC CO_2 sensors were mounted at 10 m above ground level in Dripsey (for years 2002 to 2004) and at 6 m thereafter; at 1.5 m in Wexford and at 3 m in Glencar. The N_2O gas analyser at the Cork grassland site had its air intake at 6 m above ground level while the gas analyser itself was positioned at ground level. The measured CO_2 fluxes were considered to correspond to the net ecosystem exchange (NEE), because the stored flux in the canopy was considered negligible in these treeless ecosystems. The micrometeorological convention (used in this report for EC measurements) treats fluxes from the atmosphere as negative and fluxes from the ecosystem as positive. The source area of the EC measured gas flux is called a footprint and is roughly estimated on a footprint length to sensor height ratio of 100:1.

2.4 Flux Chamber Method

The chamber technique measures gas fluxes by integrating the gas concentrations (CO_2 and CH_4 in Glencar) measurements inside a closed environment (0.6 m by 0.6 m area: in plan) over a period of time. This means that the chamber technique measures a limited number of values, typically no more than a few per day on the days that measurements are taken. As such, the chamber technique is not a continuous measurement as is the case with the EC measurements. Furthermore, the chamber measurement is applicable at the scale of the chamber size (of order 1 m) in comparison with a scale of order of 1 km for the EC technique. A set of coupled CO_2 chamber measurements was carried out for each sample plot using a portable infrared gas analyser (EGM-4, PP Systems, UK). The instantaneous NEE was first measured under a stable ambient illumination at 15-second intervals over a 60–240-second period. The same procedure was then repeated with the chamber covered with an opaque canvas cover, in order to get an estimate of the instantaneous ecosystem respiration rate (R_E). The carbon dioxide flux rates were calculated from the linear change in gas concentration as a function of time. The ecological sign convention, in which fluxes from the biosphere to the atmosphere are negative, was used for chamber work. Gross photosynthesis (P_G) was estimated as the sum of flux rate values measured in light (NEE) and dark (R_E).

The CH_4 measurement chambers (dimensions: 0.6 x 0.6m x 0.25 m) were vented (as the CO_2 chambers were) to ensure pressure equilibrium between the headspace and the outside and were equipped with fans to ensure even mixing within. Air samples were collected from the chamber headspace inside four 40-ml polypropylene syringes at 5–10 minute intervals in wintertime. Samples were stored at ambient temperature and analysed for CH_4

concentrations within 48 hours in the lab on a Shimadzu GC-14-B gas chromatograph equipped with a drierite moisture trap and a flame-ionisation detector and N_2 as the carrier gas (Laine, 2006). In order to relate the CO_2 and CH_4 gas fluxes to prevailing meteorological conditions, a set of parameters (QPAR, water level, T_{air} and T_{soil} at 5, 10, 20 and 30 cm depths) were measured at the same time as the gas exchange measurements. Continuous meteorological measurements of the EC tower stations were used to upscale chamber measurements to the ecosystem scale and to the annual timescale.

2.5 Greenhouse Gas Flux Modelling Methods

Using EC and chamber methods allows the formation of response functions between GHG fluxes and environmental variables. The response functions are created to increase the understanding of the mechanisms of CO_2 or CH_4 or N_2O gas fluxes and to establish a continuous time series of gas flux components, if intermittent chamber measurements are used. Regression modelling is based on simultaneously measured gas exchange fluxes and environmental variables, which were correlated using ecophysiologically acceptable relationships. Regression modelling is a commonly used method in integrating CO_2 fluxes due to photosynthesis and respiration (P_G and R_E) (Alm et al., 1997; Tuittila et al., 1999; Tuittila et al., 2004) and CH_4 fluxes (Juutinen et al., 2003; Saarnio et al., 1997) measured by the chamber method. Frolking & Crill (1994) used regression modelling to relate CH_4 flux in peatlands with environmental parameters. Among others, Saarnio et al. (1997) and Juutinen (2003) widened the use of the response functions into the integration and reconstruction of seasonal CH_4 fluxes. Kettunen et al. (2000) noticed that the performance of the models improved, when data from separate vegetation communities was treated separately. Saarnio, et al. (1997) used a linear model where soil temperature and water table (WT) were independent variables and had a logarithmic relationship with the flux. Juutinen et al. (2003) used non-linear functions that do not require data transformation and allow the use of different mathematical types of responses between flux and independent variables.

The CH_4 flux is the difference between CH_4 production and consumption. Both processes are temperature dependent, but have different Q_{10} values (Dunfield et al., 1993), which makes it difficult to establish an accurate relationship between temperature and CH_4 flux (Moore & Dalva, 1993). In addition, WT affects both processes but in opposite ways – lowering the WT increases oxidation and decreases production. The flux is strongly affected by WT; however, the time-lag between a change in WT and a change in flux rate (i.e. hysteresis) as well as the release of pore water complicates the relationship.

Many computer simulation models of biogeochemical cycling have been developed since the 1980s. Among them are: PaSim (Pasture Simulation) (Riedo et al., 1998), which simulates carbon and nutrient cycling in grazed grassland systems; and the DNDC (DeNitrification-DeComposition) (Li et al., 1992a, 1992b; Li, 2000), which simulates nutrient cycling in mineral soils. These models are widely used to simulate and predict emissions of GHGs from ecosystems (Calanca et al., 2007; Li et al., 2005). One of the two models used in this study (for NEE analysis) was PaSim 3.6 (v5) (Riedo et al., 1998; Riedo et al., 1999; Riedo et al., 2000; Riedo et al., 2001; Riedo et al., 2002). The second model used in this project was DNDC which is a rain-event driven and process-oriented model for simulating emissions of trace gases (NO, N_2O, N_2, CH_4, and NH_3) from soils.

3. Results – Dripsey Grassland, Co. Cork

3.1 Site Description, Management and Climate

The Dripsey grassland is located near Donoughmore (52º N, 8º 30' W) Co. Cork in south-west Ireland, 25 km north-west of Cork city. The EC tower is at an elevation of ~190 m above sea level (masl). The soil is gley (Gardiner & Radford, 1980), with the topsoil rich in organic matter to a depth of about 15 cm (about 12% organic matter), overlying a dark brown B-horizon of sand texture. The depth averaged over the top 30 cm the volumetric soil porosity was 0.49, the saturation moisture level was 0.45, the field capacity was 0.32, and the wilting point was 0.12 m^3 m^{-3}. For the top 5 cm of topsoil, the porosity was ~65%. The climate is temperate and humid with mean precipitation (over 10 years) in the region of about 1500 mm yr^{-1}. The air temperatures experienced a small range during the year going from a maximum of 20 ºC in summer to a minimum of 0 ºC in winter. The daily summer average is ~15 ºC and the daily winter average is ~5 ºC. The site experienced an annual mean wind velocity (at 3 m) of 4 m s^{-1} with 30-minute peaks up to 16 m s^{-1}. The prevailing wind is from the south-west. The land use on site is agricultural grassland. The vegetation cover is grassland of moderately high quality pasture and meadow, with the dominant plant species is perennial ryegrass (*Lolium perenne*) but with a significant fraction of clover.

The landscape in the vicinity of the site is typical of the surrounding rural area, and indeed typical of much of the Irish agricultural landscape in general. The landscape near the meteorological EC tower is partitioned into small fields ranging in size from ~1 ha to 5 ha. Management data (application of fertilisers, grazing and silage cuts) was collected through monthly surveys completed by the farmers (see Table 3.1). Livestock density at the site was 2.2 livestock units (LU) ha^{-1} in 2003 (Lewis, 2003), and has reduced in recent years. The Leaf Area Index (LAI) measurements started in 2004 and ranged from ~2 in the winter to ~6 in the summer. The annual yield of silage in the region has been 8 to 12 tonnes of dry matter ha^{-1} yr^{-1}. Grass productivity was typically enhanced with the application of approximately 300 kg ha^{-1} of nitrogen in fertiliser and slurry in 2002 and 2003 and lesser amounts from 2004 to 2008. The applications of fertiliser were spread at intervals of approximately six weeks between February and September. Commercially prepared mineral fertiliser mixtures were used, consisting of almost equal parts NH_4^+-N and NO_3^--N. The spreading rates of nitrogen in chemical fertiliser and nitrogen in slurry are shown in Table 3.1.

Table 3.1: Annual applications of nitrogen, N_2O emissions and emission ratios (ER) are the observed emissions divided by the N in mineral fertiliser.

Year	Fertilisers input, kg N ha^{-1} y^{-1}		Emission, kg N ha^{-1} y^{-1}		N_2O Emission ratio
	Artificial	Slurry	Observed	Modelled	
2002	200.30	152.23	5.2	14.46	2.6%
2003	206.81	130.30	8.43	13.84	4.2%
2004	178.62	29.78	3.99	6.06	2.2%
2005	123.73	24.76	4.81	8.03	3.9%
2006	144.27	9.37	1.99	5.81	1.4%

3.2 Meteorological Observations

One of the key drivers of ecosystem CO_2 fluxes is precipitation. Most rain falls in the winter time from October to February, with the maximum monthly rainfall recorded being 260 mm in November 2002. The average annual rainfall at this location is ~1500 mm. Another key driver of the ecosystem CO_2 fluxes is the solar radiation measured as the photosynthetically active radiation (QPAR). Typically, the daytime QPAR ranges from magnitudes of ~200 µmol m^{-2} s^{-1} in the winter months to ~550 µmol m^{-2} s^{-1} in the strong summer months. It is noted that the monthly lows in air temperature were ~0 ºC in winter and up to 20 ºC in summer months. The soil temperature follows the air temperature with a short time lag.

3.3 Eddy Covariance CO_2 Fluxes – Observations

The monthly time series of CO_2 in g C-CO_2 m^{-2} are shown in Figures 3.1 and 3.2. The months of October, November, December and January are net emissions months, while February and September are closer to neutral. The 6 months of March, April, May, June, July and August are net uptake months. The net uptake in the peak month May or June is ~-100 g C-CO_2 m^{-2} while the emission months are typically less than +20 g C-CO_2 m^{-2}. In Figure 3.2 we note a clear seasonal pattern with typical uptake in the summer months and lower emissions in the winter months. In Figure 3.3 the cumulative CO_2 fluxes in g C-CO_2 m^{-2} y^{-1} is shown. The 4 years 2002, 2003, 2005 and 2006 had a range of NEE of ~-220 to -260 g C-CO_2 m^{-2} y^{-1} (~-2.4 tC-CO_2 ha^{-1} y^{-1}) while the year 2004 was almost twice that at -390 g C-CO_2 m^{-2} y^{-1} (~-3.9 tC-CO_2 ha^{-1} y^{-1}).

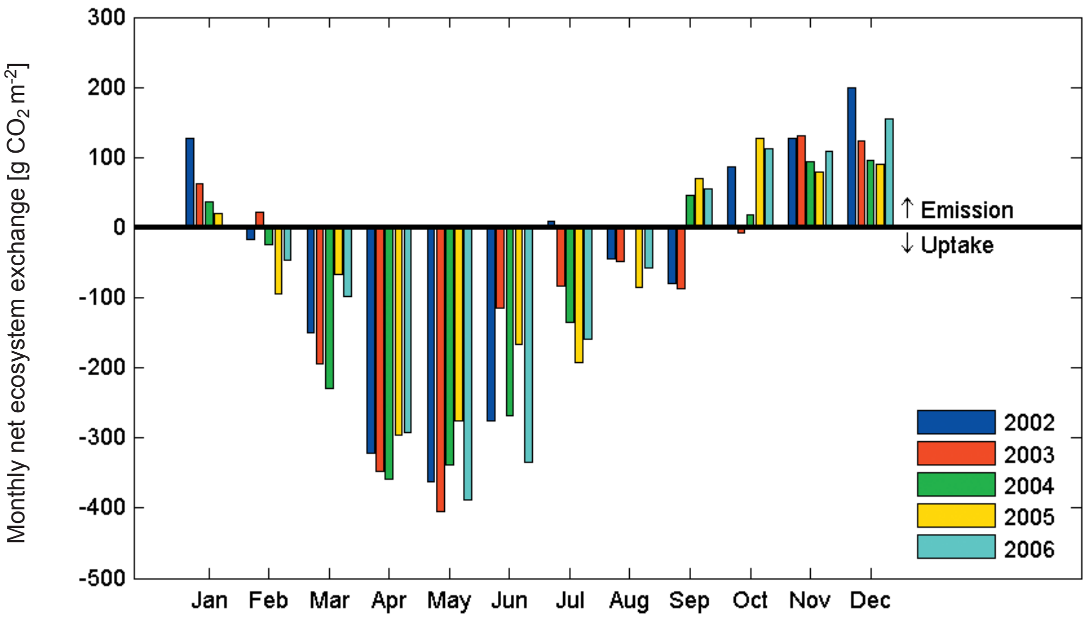

Figure 3.1: Monthly CO_2 fluxes in units of g C-CO_2 m^{-2} at the Dripsey grassland.

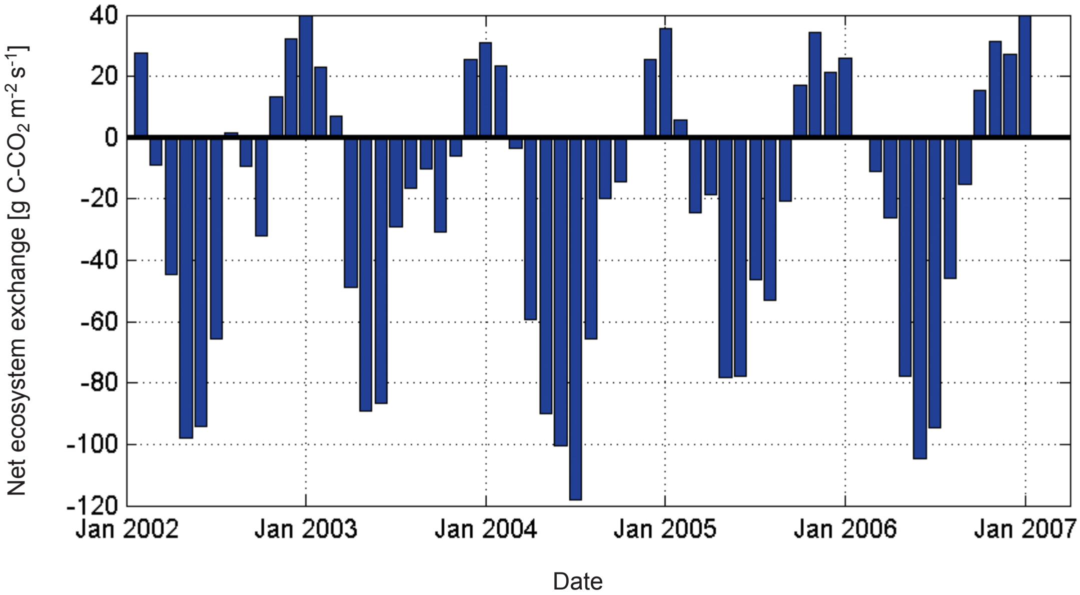

Figure 3.2: Five-year time series of monthly CO_2 fluxes in units of g C-CO_2 m^{-2} at Dripsey grassland.

3.4 Eddy Covariance N_2O Fluxes – Observations

Emissions of N_2O from soils are variable in both space and time. The cumulative emission for the years 2002 to 2006 ranged from 1.99 to 8.43 kg N-N_2O ha^{-1} y^{-1} (Table 3.1 and Figure 3.4). This includes background or non-anthropogenic N_2O emissions but these are likely to be a small proportion of the total. A global estimate of 0.5 kg N m^{-2} $year^{-1}$ for background non-anthropogenic N_2O emission was given by Bouwman et al. (1995). The emission factor observed is higher than the IPCC guideline emission factor for national GHG inventories of 1.0% (IPCC, 2007) but the wet, mild conditions at this site favour high rates of denitrification (Maag & Vinther, 1996).

3.5 Greenhouse Gas Flux Modelling

The modelled NEE using PaSim broadly agreed with the observations. The grass growing period (April to October) can be divided into an active spring growing phase up to the first major grass cut (up to June), and a less active phase thereafter. The measured and PaSim modelled (in brackets) annual uptake was -2.22 (2.6), -2.30 (2.7), 3.86 (3.4), 2.15 (3.4), 2.58 (2.8) tC ha^{-1} for the years 2002 to 2006, respectively. Those values fall within the range of values for European grassland (-0.5 to - 5 tC ha^{-1} yr^{-1}). Good agreement occurs during the growing season, with the rate of change being modelled accurately. Lawton et al. (2005) used PaSim for the above NEE modelling and also applied PaSim for simulation of the other GHGs, including CH_4 and N_2O in the Dripsey grassland. The simulation was reasonable (Lawton, 2005), suggesting PaSim is a robust process-based model for simulation of GHGs for humid temperate grasslands.

The DNDC model was used to model the N_2O emissions from the Dripsey grassland for the five years 2002 to 2006. In modelling with DNDC the project team attempted to model the different land-management practices of several farms by averaging out these practices as if dealing with only one farm. Table 3.1 summarises the N in fertiliser and slurry along with the observed and DNDC modelled N_2O fluxes for each of the five years. The annual observed fluxes range from 2.0 to 8.4 kg N–N_2O ha^{-1} yr^{-1}. The emission ratios as defined by the ratio of observed annual fluxes to the N application in artificial fertiliser ranged from 1.4% to 4.2%. These emission ratios are higher than the IPCC guideline value of 1.25 ± 1.0% (IPCC, 2001) but within the range of 0.3 to 5.8% observed by Dobbie et al. (1999) for grassland sites in the UK.

It was noted from Table 3.1 that the observed emissions for 2002 are for the second half of the year (i.e. 2.6%) and the ER is estimated assuming that half of the observed emissions occurred in the first half of the year. The predicted increase in N_2O emissions due to predicted future climate change will far outweigh the reduction in emissions expected from reduced synthetic fertiliser applications.

3.6 Discussion

The EC CO_2 fluxes at this grassland site show both seasonal and interannual variability. In the spring-summer season there is a net uptake of CO_2; in the autumn-winter there is a net emission. Integrated over the year, the flux of CO_2 has an interannual variation of -210 to -390 g C-CO_2 m^{-2} y^{-1} (-2.1 to -3.9 tC-CO_2 ha^{-1} y^{-1}). The annual N_2O fluxes ranged from 2.0 to 8.4 kg N-N_2O ha^{-1}. With an estimated background flux (due to soil processes in the absence of N fertilisation) of ~0.5 kg N-N_2O ha^{-1}, it was noted that since 2003 there has been a reduction in N_2O emissions. This is due in part to the Nitrate Directive and in part to a reduction in animal numbers (e.g. conversion of a fraction of grassland to forestry and to barley). The model study of the Dripsey grassland site using PaSim shows that the process-oriented biogeochemical model (PaSim) for carbon cycling in this grassland simulates well the EC measured NEE over the five-year study period.

Our measurements over the 5 years (2002 to 2006) of N_2O and the DNDC model simulations show the following:

1 The measured annual N_2O emission ranged from 2.0 to 8.4 kg N-N_2O ha^{-1} and the emission ratio for this humid grassland site ranged from 1.4% to 3.9%.

2 The DNDC model predicts an annual N_2O emission which ranged from 5.8 to 14.4 kg N-N_2O ha^{-1} which is always higher than the observations.

3 The DNDC model predicts that in a scenario with future climate shifts based on the IS92a scenario[1] and current N application levels, annual N_2O emission will increase by 45%.

4 In the IS92a scenario, background N_2O emission is predicted to increase by 30%.

5 Reducing current N applications by 11% (to comply with the EU Water Quality Directive) is predicted to decrease N_2O emissions by only 6%.

1 Climate modellers make assumptions about future population growth and economic development in order to estimate future GHG emissions. A portfolio of such assumptions is known as a 'scenario'. The IS92a scenario was developed for the IPCC First Assessment Report (1992). This is a middle-of-the-range scenario in which population rises to 11.3 billion by 2100, economic growth averages 2.3% per year between 1990 and 2100 and a mix of conventional and renewable energy sources are used. Only those emissions controls internationally agreed upon and national policies enacted into law are included.

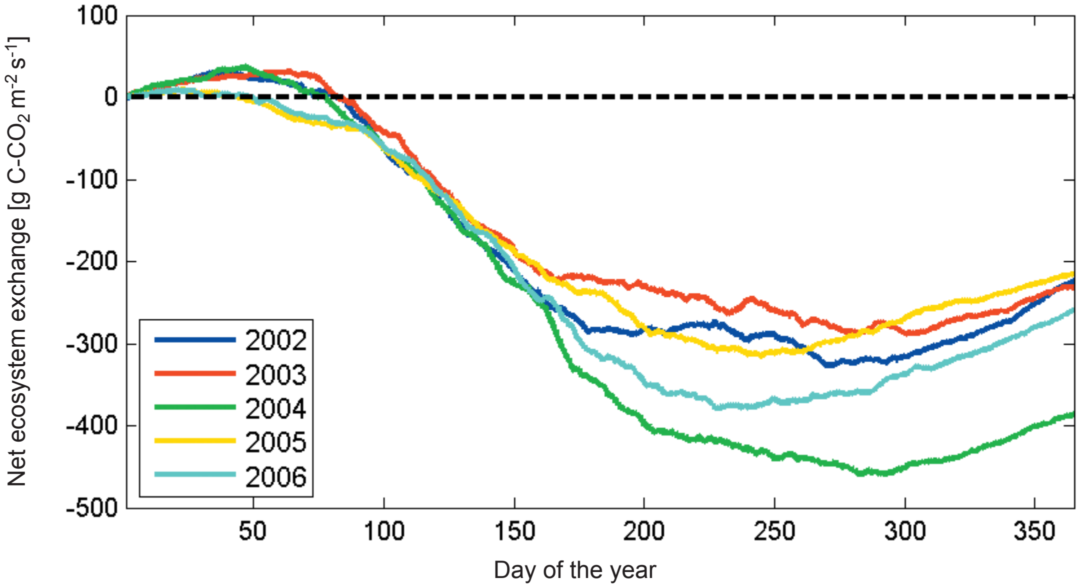

Figure 3.3: Cumulative sums of the CO_2 fluxes given in units of g C-CO_2 m^{-2} at Dripsey grassland.

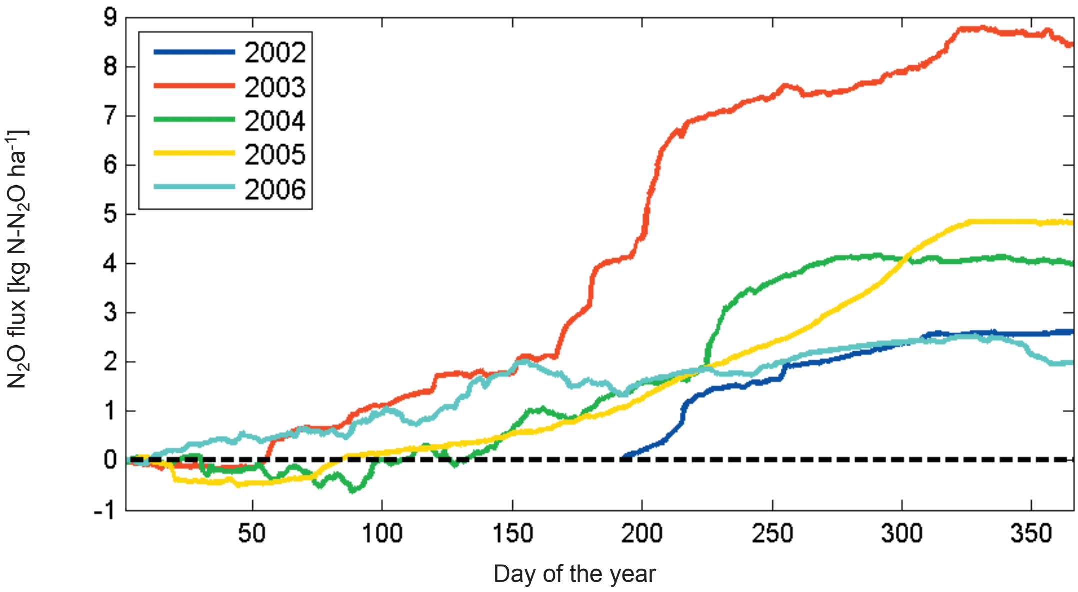

Figure 3.4: Cumulative fluxes of N_2O in units of kg N-N_2O ha^{-1}. Over the five years (2002 to 2006), annual N_2O emission ranged from 1.6 to 8.6 kg N-N_2O ha^{-1} y^{-1} at Dripsey grassland.

4. Results – Johnstown Castle Grassland, Co. Wexford

4.1 Site Description, Management and Climate

The study site is at Johnstown Castle Estate, Co. Wexford, Ireland (52˚ 18’ N; 6˚ 30’ W). The Wexford grassland is situated at an elevation of about 58 masl. The types of soils falling within the EC footprint are brown earths and gleys and categorised as ‘free draining’. The climate is temperate and humid with a mean annual precipitation in the Wexford region of about 1002 mm. Daily air temperatures have a very small range of variation during the year, going from a maximum of 24 ºC to a minimum of -2 ºC, with an average of 15 ºC in summer and 6 ºC in winter. The mean fetch to height ratio calculated by the footprint model was 215, which would be ~150 m if the simple ratio of 1:100 for sensor height to fetch was used. A photograph of the site with the EC tower in the foreground is shown in Figure 4.1.

The measurement area was a grassland (predominantly *Lolium perenne*) divided by wire fences into paddocks. Approximately half of the area was used for growing grass silage and grazed after the silage harvest for the rest of the year and half was grazed, typically from mid-February to late November. The silage paddocks were harvested once or twice per year, once in late May or early June. When a second harvest is taken, it occurs in early August. Nitrogen inputs in 2004 were approximately 240 kg N ha^{-1}, half of this as urea, applied early in the growing season, and half as calcium ammonium nitrate (CAN) applied after the first cut silage. After the first grass harvest of 2006, two paddocks were harrowed to 5 cm depth and sown with kale (*Brassica oleracea*) for winter forage and were subsequently reseeded with grass. After the first harvest of 2007, two other paddocks were sown with kale. Winter forage crop rotations are grown on managed temperate grasslands but there have been few studies of how these rotations affect the CO_2 fluxes between these ecosystems and the atmosphere.

Figure 4.1: EC tower at Wexford grassland at Johnstown Castle grassland. Ecosystem is predominantly grassland with some arable fraction (from 2006 onwards). Foreground shows grassland; background shows winter kale forage crop over a fraction of EC footprint. EC instruments (sonic anemometer and Licor CO_2/H_2O gas analyser) are located at a height of 1.5 m above the ground, suggesting an average footprint extent of about 150 m in the south-west direction away from the tower. Grassland is laid out in paddocks.

4.2 Meteorological Observations

There was considerable interannual variability in the environmental parameters (rainfall, QPAR, soil temperature and soil moisture). In 2003, the soil moisture remained high until early June, then decreased during the first half of June. Heavy precipitation in late June and early July led to higher soil moisture contents from late June through to the start of August, followed by another dry period. The summer of 2003 was warm and wet during June and July. While precipitation was extremely low in August 2003, summer 2004 was much drier, with volumetric soil moisture content remaining below 40% for much of May, June and July. Both 2005 and 2006 were characterised by heavy spring and early summer precipitation, with high soil moisture levels persisting until early June of each year. After a relatively dry April, the summer of 2007 was extremely wet compared to other years, with high amounts of precipitation received in May and August. Soil moisture content remained above 40% from early May until early August. In general the surface soil was close to saturation (~65%) for the winter months and fell to as low as 25% in some parts of the late springs and summers, but was very much dependent on the timing and the amount of rainfall.

4.3 Eddy Covariance CO_2 Fluxes – Observations

The NEE was continuously measured by an EC system from October 2002 to December 2007. Figure 4.2 presents the monthly CO_2 fluxes measured by the EC system in units of g C-CO_2 m^{-2}. A net uptake was present for most months of the year except January and December. It is relevant to note that winter kale made up > half the EC footprint from June 2006 onwards. The effect of the kale is significant. For the years when grassland occupied 100% of the footprint (2003, 2004 and 2005), the monthly CO_2 magnitudes are similar year on year. However, once the kale was set there was a significant reduction in the CO_2 uptake in the summer of 2006 and 2007 and a corresponding increase in the winter emissions of CO_2 for the winter of late 2006 and 2007. Kale is a short cabbage-like crop. When mature, the cattle are allowed to graze the kale during the latter end of the year. Figure 4.3 shows the clear impact of kale on the CO_2 response after June 2006.

Figure 4.4 illustrates the cumulative CO_2 flux for each of the 5 years in g C-CO_2 m^{-2} y^{-1}. The calendar year 2003 had the highest CO_2 uptake at -582 g C-CO_2 m^{-2} y^{-1} (or -5.82 t C-CO_2 ha^{-1} y^{-1}) in a year when the ecosystem footprint was 100% grassland. The other two grassland years (2004 and 2005) were a little less productive at -410 and -460 g C-CO_2 m^{-2} y^{-1}. In the subsequent 2 kale years the NEE uptake drops significantly to -220 and -130 g C-CO_2 m^{-2} y^{-1} in 2006 and 2007 respectively. A net uptake of CO_2 by the ecosystem was observed in all years of the study.

4.4 Discussion

The April CO_2 fluxes from the Wexford site in 2007 were within 20% of those observed in the Aprils of 2002–2005 despite much lower precipitation. Soil moisture content remained close to the levels of previous years during April of both 2006 and 2007. The soil remained wet throughout summer 2007 due to heavy rainfall in June, July and early August. The June CO_2 fluxes varied during 2002-2005, due to variation in harvesting dates. There was a net emission of CO_2 flux at Wexford during the extremely wet June of 2007; however this is likely to be at least partially due to the reseeding of part of the measurement area with winter kale. QPAR was also below average in June of 2007. June 2005 and 2006 also saw net emissions of CO_2 under different climatic conditions (higher QPAR and drier soils) to 2007 but similar management conditions. CO_2 uptake for July 2007 was less than previous years; for the remainder of 2007 small monthly uptakes or emissions were observed. This may be due to the extremely wet conditions following the 2007 harvest. The autumn and winter monthly fluxes in 2006 and 2007 show markedly lower uptakes than other years or net CO_2 emission in some months. This may be attributable to the effect of planting the winter kale crop in June 2006 and June 2007 in part of the EC footprint area. Strong CO_2 uptakes were measured in August and September 2005. Under a grassland management system for three years, 2003, 2004 and 2005, the Wexford site had CO_2 uptakes that were -582, -410 and -460 g C-CO_2 m^{-2} y^{-1} respectively. Under the winter kale crop for the two years, 2006 and 2007, the uptakes were significantly lower at -220 and -130 g C-CO_2 m^{-2} y^{-1} respectively.

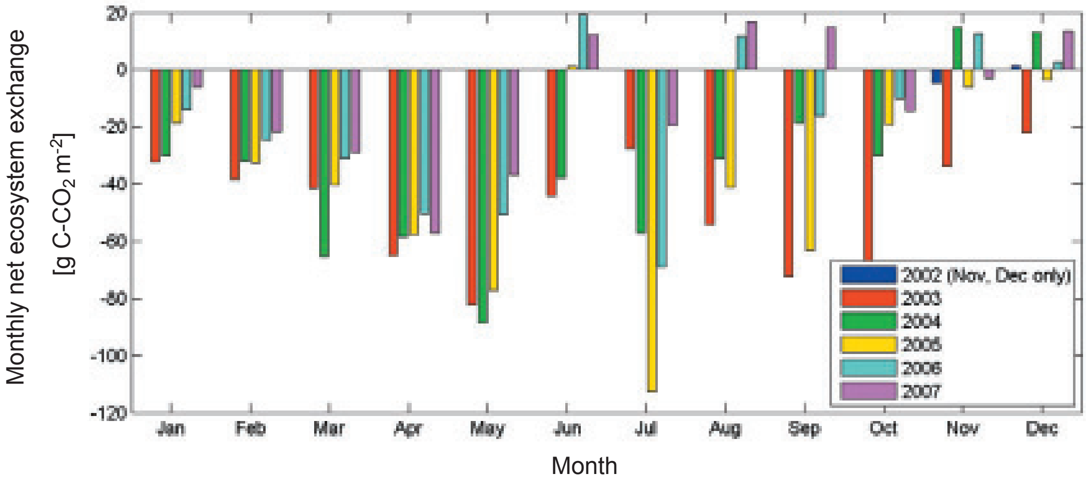

Figure 4.2: Monthly CO_2 fluxes in units of g C-CO_2 m^{-2} at Wexford grassland.

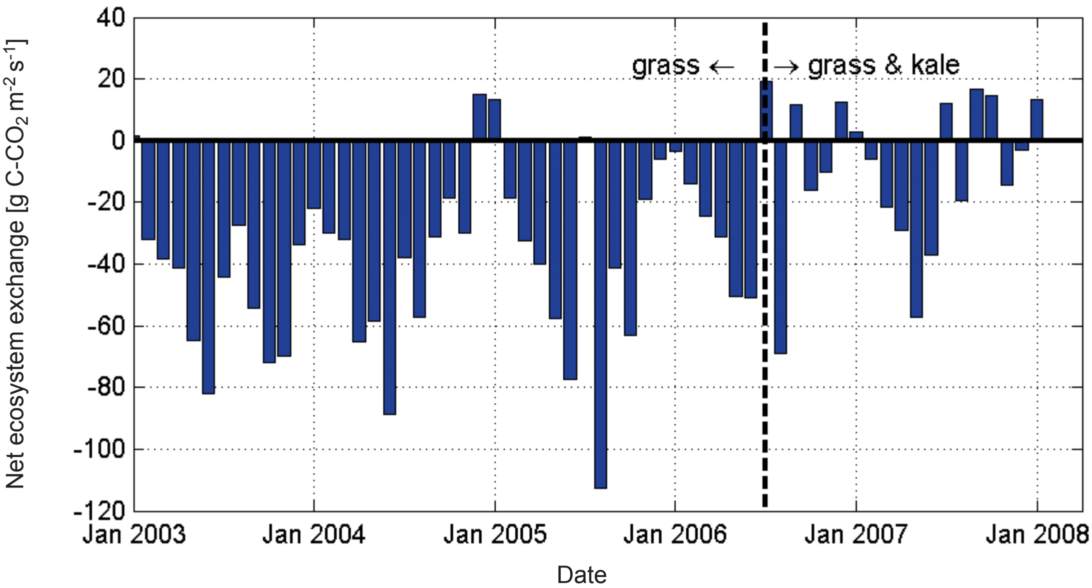

Figure 4.3: Five-year time series of monthly sums of CO_2 fluxes given in units of g C-CO_2 m^{-2} at Wexford grassland. Note that winter kale was planted in June 2006: due to ploughing and cattle grazing the kale in the following winters, this had a significant impact on reducing CO_2 uptake in comparison with the grassland of earlier years.

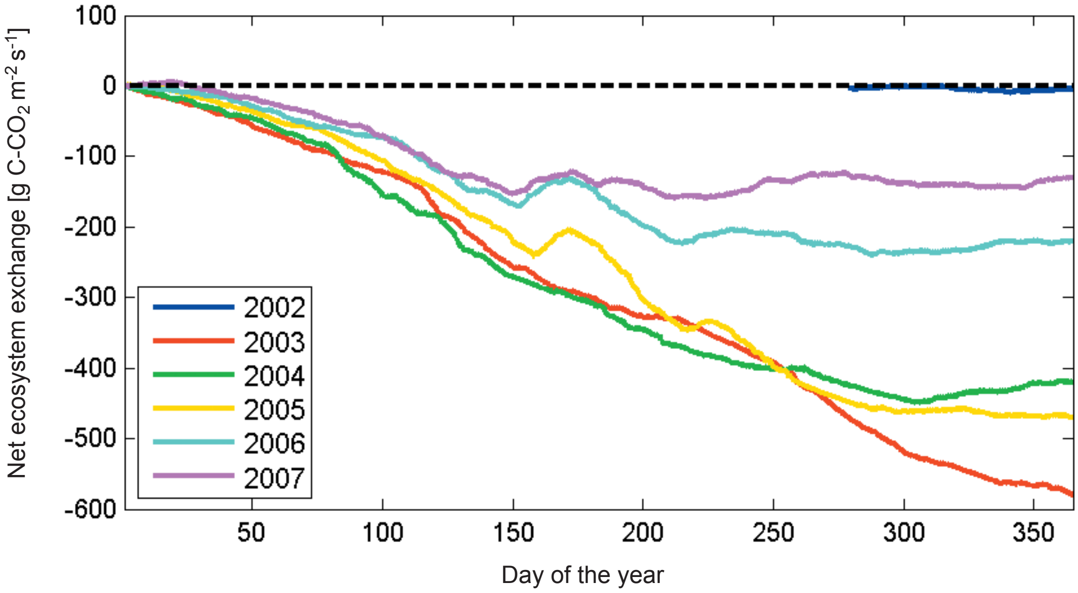

Figure 4.4: Cumulative sum of the CO_2 fluxes given in units of g C-CO_2 m^{-2} at Wexford grassland.

5. Results – Atlantic Blanket Peatland, Glencar, Co. Kerry

5.1 Site Description, Climate and Soil

The third EC tower site was an intact Atlantic blanket bog at Glencar, Co. Kerry, in south-west Ireland (51° 55' N; 9° 55' W). The site is relatively flat and positioned in a valley at an elevation of between 145 and 170 masl and lies on sandstone bedrock. The peat depth is > 2 m within the EC footprint. The characteristic feature of the bog is a spatially heterogeneous surface, with a mosaic of microforms, differing in relative altitude, plant composition and water table level.

These microforms were divided into four classes based on relative elevation: hummocks (HU), high lawns (HL), low lawns (LL) and hollows (HO). The elevation difference between the highest (HU) and lowest (HO) microform is typically 20 to 40 cm. HO are depressions covered with water. The microform composition inside the EC footprint was estimated as 4% (HU), 58% (HL), 25% (LL) and 13% (HO) (Laine et al., 2006). The vascular plants cover about 30% of the peatland area, mainly *Molinia caerulea* (purple moor-grass), *Calluna vulgaris* (common heather), *Erica tetralix* (cross-leaved heath) and *Narthecium ossifragum*

(a)

(b)

Figure 5.1: Blanket peatland at Glencar, Co. Kerry: (a) view of Glencar Atlantic blanket bog with a hummock and hollow in the foreground; (b) view with the predominant lawn vegetation.

(bog asphodel) (Sottocornola et al., 2008). The bryophyte component covers about 25% of the peatland and the dominant species include *Racomitrium lanuginosum* (woolly-hair moss) and *Sphagnum spp.* (bog mosses). The leaf area index (LAI), since the autumn of 2005 was between 0.2 in winter and 0.6 m^2 m^{-2} in summer. Two photographs of the site are shown in Figure 5.1.

5.2 Meteorological Observations

All analysis was based on the hydrological year (1 Oct to 30 Sept). Precipitation was abundant throughout the year (~2500 mm per year) with typically very high rainfall in the winter and autumn. The water table follows the precipitation pattern with a range of level of only about 20 cm. The coldest month of the year was February, with monthly temperatures ranging between 5.6 and 6.9 ºC over the five years, while the warmest months were July and August, with a monthly maximum of 16.4 ºC. The monthly averaged soil temperature at a depth of 20 cm is similar to the air temperature but the diurnal fluctuations are not as high.

5.3 Eddy Covariance and Chamber CO_2 and CH_4 Fluxes – Observations

The monthly EC NEE for the peatland is shown in Figure 5.2. Five of the twelve months (May to September) are uptake months in all five years. The largest uptake month was July 2005 (~38 g C-CO_2 m^{-2}). For 2007, we note a stronger emission in the winter and spring months, while 2003 showed the lowest winter CO_2 loss. This different pattern was likely due to the high temperature and deep water table (meaning drier conditions) in 2007, which increased the decomposition processes. The lower temperature and higher WT level were likely to have slowed decomposition in the winter of 2003. The highest CO_2 uptake in the summer was recorded in 2005 from May to August. Figure 5.3 presents the five-year time series of monthly CO_2 fluxes and underlines the strong seasonal and interannual variability. Figure 5.4 shows the cumulative NEE for the five hydrological years. The cumulative NEE uptake ranged from a low of -17 g C-CO_2 m^{-2} (0.17 t C ha^{-1}) for the year 2006/2007 to a high of -97 g C-CO_2 m^{-2} (-0.97 t C ha^{-1}) for the 2004/2005 year. Although small when compared to grassland NEEs in absolute terms, this is a large relative range that indicates considerable CO_2 interannual variability. This indicates that the peatland is subject to significant interannual variability of CO_2 even though there was only mild environmental interannual variability between 2002 and 2007. This suggests that if there were significant environmental variability (i.e. climate change) then the peatland NEE fluxes might either become a source for carbon or a strong sink (as it did in 2004/05). The NEE fluxes suggest that the peatland is a sensitive environment and may suffer rapid change in the event of climate change.

The carbon balance of the peatland includes: the carbon uptake of the CO_2 flux from atmosphere to the biosphere; the carbon in the CH_4 flux from the biosphere to the atmosphere; and the carbon lost as dissolved organic carbon (DOC) in the peatland stream. The inclusion of components (CH_4 and DOC) could turn the bog ecosystem from a net sink to a net source of carbon.

During the period June 2003 to September 2005, CO_2 and CH_4 fluxes of the Glencar intact Atlantic blanket peatland were studied using the chamber method (Laine, 2006). A seasonal variation was observed in NEE within and between the different microforms. Both uptake and release of CO_2 were highest in the drier microforms (HU and HL), which acted as a sink of CO_2 except in winter months from November to February. The highest uptake of CO_2 occurred in mid-summer, i.e. July. The vegetation of the wet microforms (LL and HO) was less dense and had a shorter growing season, which had its smaller monthly NEE values. Especially in the LL microform, the uptake of CO_2 began noticeably later than in the other microforms. There was little difference in chamber measured CO_2 fluxes between the summers of 2003 and 2004.

The CH_4 efflux shows both spatial and temporal variation between and within the microforms (see Laine, 2007). The spatial variation is related to differences in water table depth and vegetation composition. Seasonal variation is related to these factors but also to soil temperature and seasonal changes in green leaf area that is one of the

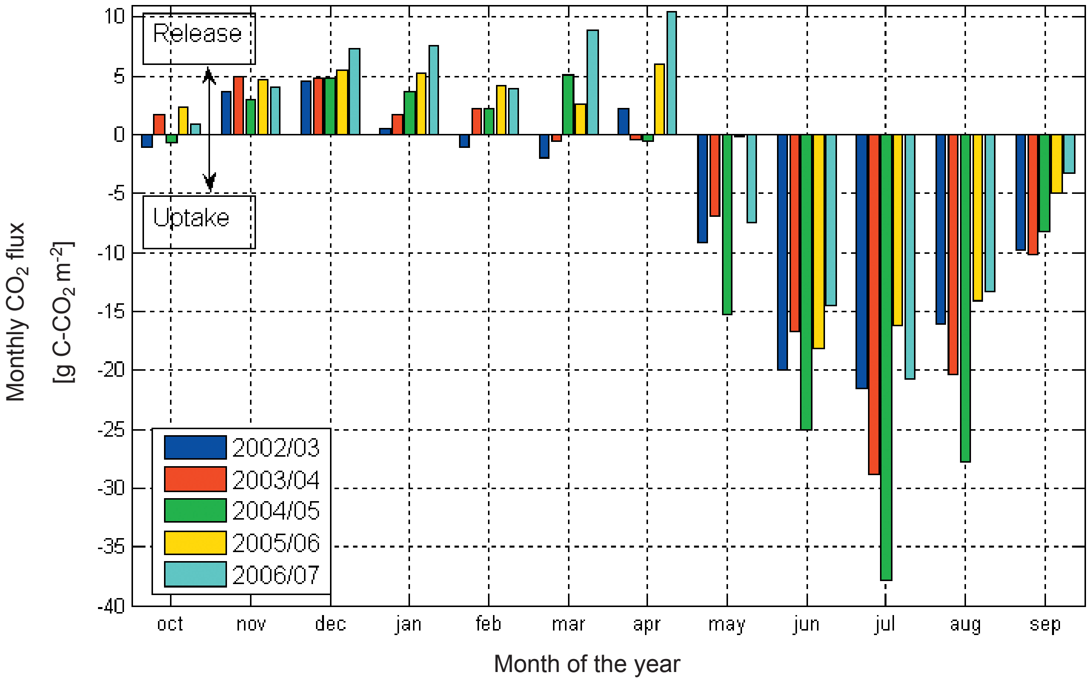

Figure 5.2 Monthly CO_2 fluxes in units of g C-CO_2 m^{-2} at Glencar peatland for five hydrological years.

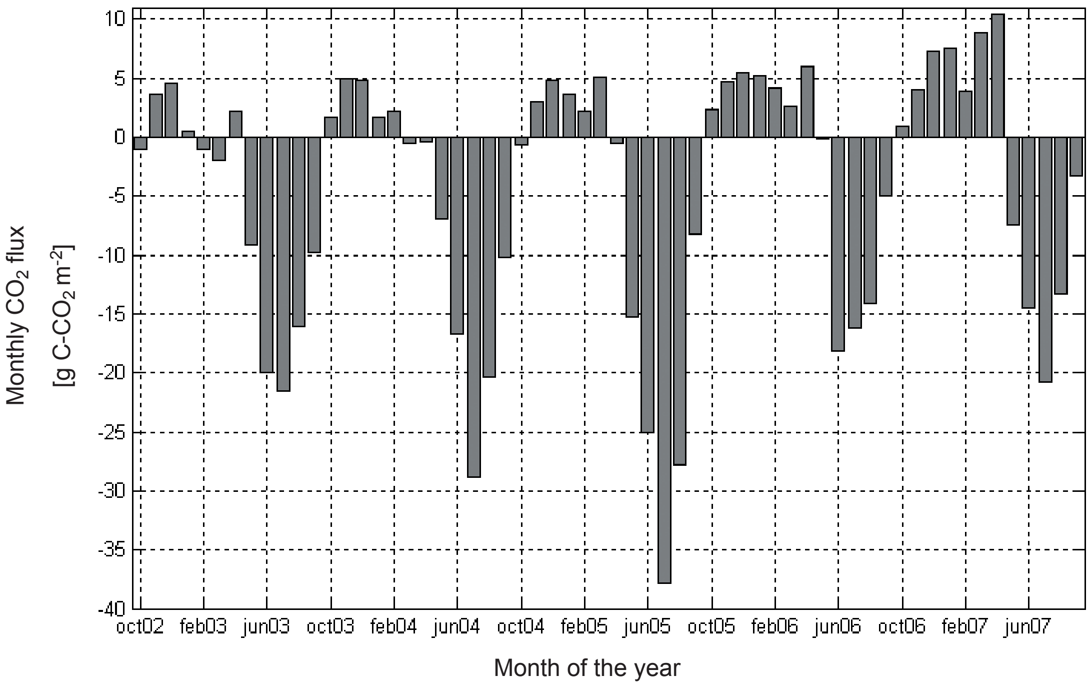

Figure 5.3: Five-year time series of the EC measured monthly CO_2 fluxes in g C-CO_2 m^{-2} at Glencar peatland. The seasonal (summer vs. winter) differences are very clear; interannual variability is also clearly visible.

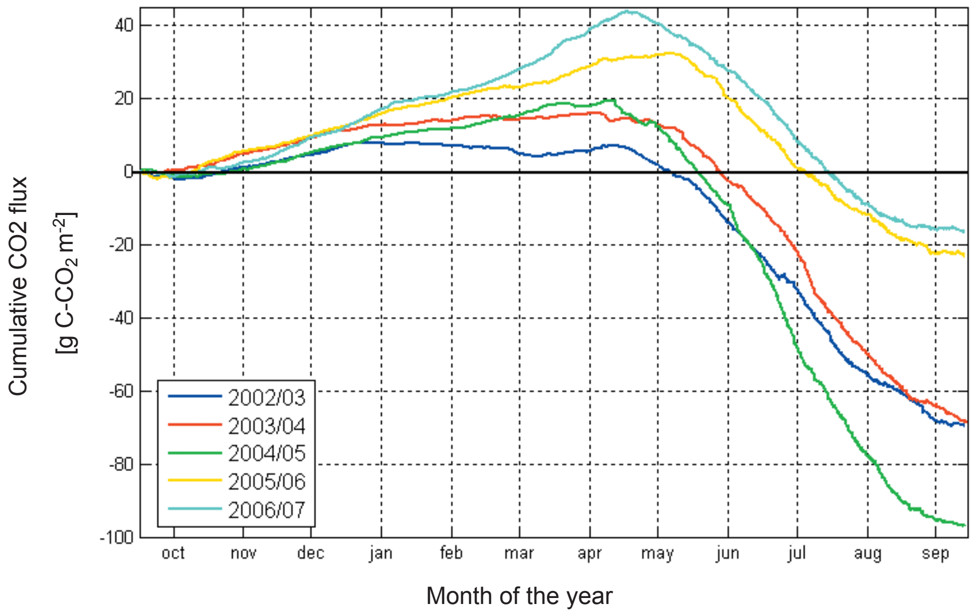

Figure 5.4: Cumulative uptake of CO_2 in g C-CO_2 m^{-2} at Glencar peatland for five hydrological years. Cumulative net ecosystem exchange uptake ranges from -17 to -97 g C-CO_2 m^{-2} (-0.17 to -0.97 t C ha^{-1}).

key factors determining the amount of freshly produced compounds used by the methanogenic bacteria. The mean CH_4 emission fluxes for different microforms were 11.8, 19.2, 20.9 and 50.4 mg m^{-2} day^{-1} for HU, HL, LL and HO, respectively, suggesting that the wet hollows emit five times more CH_4 than the dry hummocks. As the footprint is composed of 13% hollows, this microform is significant in its ability and potential to emit CH_4. For the time period 1 October 2003 to 30 September 2004 the chamber measurements area upscaled NEE estimates and CH_4 fluxes were -65 and 4.7 g C m^{-2}, respectively. This is based on average microform distribution in the peatland area: 6, 62, 21 and 11% for HU, HL, LL and HO respectively. The methane flux was 7.8% of the magnitude of NEE in terms of carbon.

5.4 Discussion

The CO_2 fluxes in the Glencar Atlantic blanket bog measured over a five-year period showed a large seasonal and interannual variation. The interannual variation ranged between an uptake of -0.17 to -0.97 t C-CO_2 ha^{-1} with an average of -0.55 t C-CO_2 ha^{-1}. As the WT is persistently high, decomposition was expected to be lower and therefore CO_2 uptake higher than in boreal raised bogs. However, other processes are likely to reduce the impact of the elevated water table in terms of CO_2. These are: (i) lower LAI and lower moss cover in the blanket bog, and therefore lower gross ecosystem production and CO_2 uptake compared to boreal raised bogs; and (ii) higher litter decomposition rate of the plant species in the blanket bogs, and therefore lower CO_2 uptake than in boreal raised bogs. Although Glencar has a mild maritime climate, the blanket bog is a net sink for CO_2 for only five months of each year. The CO_2 uptake by the peatland is five to ten times less than the CO_2 uptake at the grassland sites of Wexford and Dripsey (see Sections 3 and 4). The monthly uptake is about half to one-third of the uptake values in mid summer at the grassland sites. A key difference between the grassland sites and the Glencar peatland is that the grasslands are fertilised, grazed and harvested, none of which occurs in the peatland. The grassland's productive season is from about March to September (about seven months) while in the peatland the productive season is shorter, from May to September (five months). The NEE measured during the hydrological year 2003/2004 with the EC system (-0.69 t C-CO_2 ha^{-1}) was very close to that measured and scaled up to the ecosystem level with the chambers methods in the same time period (-0.65 t C-CO_2 ha^{-1}).

6. Inter-site Comparison – Discussion and Conclusions

6.1 Inter-site Meteorological Comparisons

Table 6.1 shows the magnitude of the annual precipitation at the three sites. Glencar had by far the largest amount of annual rainfall and Wexford the least. The annual average over the experimental period was 2571 mm at Glencar, 1402 mm at Dripsey and 1110 mm at Wexford. There were very little interannual precipitation differences at Wexford, with its range being from 1026 mm to 1240 mm, while at Dripsey the interannual variability ranged from 1178 mm to 1823 mm. The level of radiation at Glencar and Wexford is similar and Dripsey is the lowest of the three. Wexford and Glencar have very similar temperatures while Dripsey was almost 1 ºC lower. Glencar has warmer winters than either Dripsey or Wexford due probably to the warming influence of the Atlantic Ocean. The warmest summer was 2006 and the coldest winter was 2005/06.

6.2 Inter-site Comparison of CO_2 Fluxes – Interannual

Figure 6.1 and Table 6.1 present the annual CO_2 fluxes for the five years at the three sites. All three were sinks for CO_2 for all five years. The annual average was lowest at Glencar at ~-0.6 t C ha^{-1} y^{-1} while the average at Dripsey was -2.6 t C ha^{-1} y^{-1} and at Wexford was -3.6 t C ha^{-1} y^{-1}. It is important to note that the effect of the winter kale crop planted in June 2006 and June 2007 had a significant effect on reducing the fluxes at Wexford in the years 2006 and 2007. The shortest growing season is at Glencar at about five months while there is a seven-month growing season at Dripsey and a nine-month growing season at Wexford.

Table 6.1: Annual precipitation (mm) and the annual CO_2 uptake (tC-CO_2 ha^{-1} y^{-1})

Year	**Annual Precipitation in mm**			**Annual Uptake of CO_2**		
	Dripsey	Wexford	Glencar	Dripsey	Wexford	Glencar
2002	**1823**			-2.2		
2003	1178	1079	2510	-2.3	**-5.8**	-0.66
2004	1341	1026	2355	**-3.9**	-4.2	-0.73
2005	1328	**1240**	2468	-2.1	-4.7	**-0.92**
2006	1363	1159	**2951**	-2.6	-2.2	-0.24
2007	1383	1047	2235		-1.3	-0.17

6.3 Observations and Discussion

At the Glencar peatland, for the past five years, the site has been a small sink for CO_2 of -0.2 to -0.9 tC ha^{-1} y^{-1}. This peatland is a sensitive ecosystem and vulnerable to small changes in precipitation and radiation. This may be a portent of things to come with climate change where climate models predict increased precipitation and increased temperature over Ireland. Under the latter circumstances, this blanket peatland will possibly become a source for CO_2. Furthermore, it is likely that any disturbance (grazing, turf cutting, forest planting and water table drawdown) will transform the peatland into a source of carbon.

At the Dripsey grassland, for the past five years, the site has been a sink for CO_2 of -2.1 to -3.9 t C ha^{-1} y^{-1}. The Dripsey site is intensively managed grassland at an elevation of ~190 masl. Although the annual precipitation ranged from 1178 to 1823 mm, this large range did not impact on the CO_2 fluxes. This suggests that this site is robust to precipitation changes. As for predicted increases in summer temperatures (under climate change), this site is likely to experience an increased length to its growing season with consequent increase in CO_2 uptake. However, it was noted that the timing of silage cutting does have an impact on the annual sums of fluxes. When the first cut silage is early (late May or early June), the following three weeks or so is a period of net CO_2 emissions (due to the presence of bare soil), with the consequent reduction in the annual sum of CO_2. Sometimes, a later first cut silage (mid-June onwards) is followed also by a two to three-week period of net CO_2 emissions but these are less than the emissions from an early (May) silage cut. The impact of a late first cut also extends the length of the active growing season and so enhances the annual CO_2 uptake.

At the Wexford grassland, for the years 2003, 2004 and 2005, the site has been a sink for CO_2 of -5.8, -4.2 and -4.7 tC ha^{-1} y^{-1} respectively. For the following two years (2006 and 2007) winter kale was planted in June over about much of the EC footprint and the site became a much smaller sink for CO_2 of -2.2 and -1.3 tC ha^{-1} y^{-1} respectively. In a changing climate, with wetter winters, Wexford may become more like Dripsey in the winters. In a changing climate with warmer drier summers, the Wexford ecosystem is likely to suffer drought and moisture stress, which may lead to reduced productivity and reduced CO_2 uptake. The consequences of the predicted climate change for Wexford are a less viable grassland ecosystem.

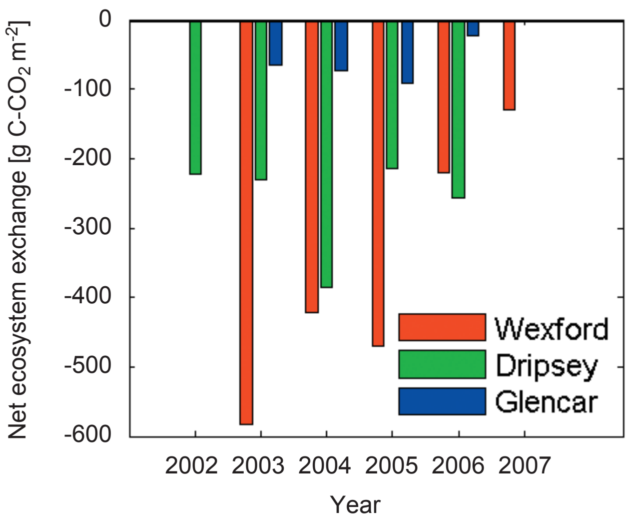

Figure 6.1: Annual EC C-CO_2 fluxes at the three sites: (a) Wexford; (b) Dripsey and (c) Glencar Bog.

7. Observations and Recommendations

Observation 1: The Atlantic blanket bog in Glencar is currently a small sink for CO_2 and a very small sink for carbon (as made up of CO_2, CH_4 and DOC), which is possibly to become a source for CO_2 under climate change. Should blanket peatlands become sources for carbon, huge stores of carbon locked up in these peatlands will begin to be lost to the atmosphere.

Recommendation 1: The setting-up of a national committee, charged with steering Ireland through this possible carbon-loss scenario in peatlands. Furthermore, there is a need to assess the source/sink status of peatlands suffering different degrees of disturbance.

Observation 2: The wet, poorly draining grassland site at Dripsey is a robust sink for CO_2 under a wide range of interannual variability in rainfall. Under climate change, wetter winters are unlikely to reduce the CO_2 uptake, but warmer summers may enhance the CO_2 uptake. The current practice of nitrogen fertilisation leads to N_2O emissions, reducing the benefit of CO_2 uptake by ~20%. However, lower N fertilisation may also reduce the CO_2 uptake by reducing the ecosystem's gross primary production (GPP).

Recommendation 2: To increase the CO_2 uptake and reduce the N_2O emissions from grasslands, alternative grassland management practices to widespread N fertilisation and silage making should be examined. These might include: reduction of N in accordance with the EU Nitrate Directive; wider use of less intensive grassland management practices, such as REPS; wider use of clover grasses (as an N fixer); later first cut silage which would extend the growing season length and enhance CO_2 sink.

Observation 3: The free draining soils at the Wexford grassland enable the site to have a net CO_2 uptake for most months of the year, even in winter. This long growing season (longer than Dripsey by up to 2 months) further enables the Wexford site to have a net annual CO_2 uptake of about 30% higher than in Dripsey. However, the practice of growing winter fodder crops (kale) has the effect of reducing summertime CO_2 uptake, and hence annual CO_2 uptake. Under climate change with wetter winters, the current CO_2 winter uptake is likely to reduce and may become net CO_2 emission in winter. With warmer summers under climate change, drought conditions with moisture stress are likely and will reduce the summer CO_2 uptake, possibly becoming a source for CO_2 in the summer. The effect of climate change is likely to reduce the net annual CO_2 uptake.

Recommendation 3: As predicted, climate change is likely to affect the viability of grassland in the free draining soils in dry regions, it is recommended that there are continuing flux experiments in this region, with particular attention paid to the effects of winter forage crops.

Observation 4: There was interannual variability of CO_2 fluxes at all sites as noted during the five years when there was little precipitation and radiation interannual variability at Glencar and Wexford. There was appreciable interannual variability in rainfall in Dripsey. With projected climate change, interannual variability is likely to increase with unknown effects on CO_2 uptake.

Recommendation 4: Continue the long-term CO_2 (and other GHGs) flux experiment so as to track the future interannual variability (of climate and GHG fluxes) and provide data for modelling the future impact of changes. New experiments should be initiated on a greater number of sites to include variation in soil type and a wider geographical representation to be representative of of Ireland.

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Journal Papers from CELTICFLUX Project

Seventeen peer-reviewed papers in international journals have been published since 2003 from this and other projects.

In Review/In Preparation

1 Leahy, P. and Kiely, G. (2008). Effects of a winter forage crop rotation on CO_2 fluxes at a managed grassland (in preparation).

2 Sottocornola, M. and Kiely, G. (2008). Hydro-meteorological controls on CO_2 eddy-covariance flux measurements in an Irish blanket bog (submitted *Agriculture and Forest Meteorology*).

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Acronyms

DNDC	denitrification decomposition model (for carbon and nutrient cycling in grasslands and wetlands)
DOC	dissolved organic carbon
EC	eddy covariance
GHGs	greenhouse gases
GPP	gross primary production
Gt	giga tonne
GWP	global warming potential
IRGA	infra red gas analyser
masl	metres above sea level
NEE	net ecosystem exchange
NGE	net greenhouse gas exchange
PaSim	pasture simulation model (for carbon and nutrient cycling in grasslands)
P_G	gross photosynthesis
QPAR	photosynthetically active radiation
R_E	ecosystem respiration
REPS	Rural Environmental Protection Scheme
$tC\text{-}CO_2\ ha^{-1}\ yr^{-1}$	tons of carbon per hectare per year
TGA	trace gas analyse (for CO_2 and H_2O)

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Agriculture and Food Development Authority

Strategy for Science, Technology and Innovation

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