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PRIME REAL ESTATE FOR CLIMATE CHANGE MITIGATION: REWETTED INDUSTRIAL CUTAWAY PEATLANDS IN NORTH WEST IRELAND

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SUMMARY

The potential for rewetted peatlands to be utilised in climate change mitigation was examined at an industrial cutaway peatland in North West Ireland. In 2003, following the cessation of milled peat extraction at the study site, the drainage ditches were blocked, peat ridges were constructed and the peatland surface was landscaped to maximise water retention. Since then, extensive re-colonisation of the bare peat surface has taken place and a range of vascular and bryophyte communities exist between rapidly decreasing areas of open water and small remnants of bare peat. Carbon dioxide (CO_2) fluxes were measured over a three year period (2009-2011) in a range of microsites within the rewetted peatland. All vegetated microsites were a sink for CO_2 and suggest that these formerly degraded peatlands located within a region of relatively high rainfall and cool temperatures may be “prime real estate” for climate change mitigation and/or carbon (C) offset projects.

KEY WORDS: Carbon dioxide, climate change, methane, rewetting.

INTRODUCTION

Damaged peatlands are a significant source of CO_2 to the atmosphere and the restoration of damaged peatland ecosystems has been suggested as one of the most cost effective ways of reducing greenhouse gas (GHG) emissions and mitigating the effects of climate change (Parish et al. 2008). Over 80% of Irish peatlands have been damaged to some extent (Renou-Wilson *et al.* 2011). These range from peatlands that have undergone relatively minor damage, where some of the ecosystem functioning remains relatively intact (e.g. low impact traditional hand cut peat extraction in some blanket bogs) to peatlands that have undergone extreme damage and where much of ecosystem functioning has been destroyed (e.g. industrial cutaway peatlands). In the latter category, restoration of the main ecosystem functions, in particular the ability to actively sequester and store C, presents a major challenge. Rewetting of industrial peatlands and subsequent recolonisation by desirable plant species have been shown to lead to a reduction in CO_2 emissions (Waddington and Warner

2001*)* and a return to C sequestration (Tuittila *et al.* 1999). In this study, we investigated CO_2 exchange over a three year period in a rewetted industrial cutaway peatland located in a region characterised by high rainfall, cool temperatures and a prolonged growing season.

MATERIAL AND METHODS

The study site was located at Bellacorick, Co. Mayo, Ireland (Latitude: 54° 7' N, Longitude: 9° 35' W). From 1960 to 2003, the peat was industrially extracted by milling for electricity generation. Between 1996 and 2002, small-scale rehabilitation test areas were established at the site and following the cessation of peat extraction in 2003, a larger-scale rehabilitation plan was implemented in a sequential fashion across the peatland. This resulted in (1) a rise in the water table level over large areas of the peatland and (2) recolonisation of the bare peat substrate by a range of vascular and moss communities. Residual depth of peat of the study area is around 50cm and the peat is mainly composed of highly humified cyperaceous peat overlying a glacial till substrate. pH ranges between 3.8 to 6.4 and the C:N ratio is 58. The climate of the area is characterised by prevailing south westerly winds, a mean annual rainfall of 1143 mm and a mean annual temperature of 9.3°C (Met Éireann – Belmullet Station, 1961-1990).

Environmental variables

Perforated PVC pipes were inserted to measure water table position (WT). Wooden boardwalks were built to minimise damage to the vegetation and to avoid compression of the peat during gas sampling. Data loggers (Micrologger Model 4R, Zeta-tec, Durham, U.K.) recorded hourly soil temperatures at 5, 10 and 20cm depths. A weather station (WatchDog Model 2400, Spectrum Technologies Inc., Illinois, U.S.A) was programmed to record photosynthetic photon flux density (PPFD, $\mu mol\ m^{-2}\ s^{-1}$) every 10 minutes using Spec 8 Pro software (Spectrum Technologies Inc., Illinois, U.S.A). Permanent stainless steel collars (60 x 60cm) were established for gas sampling within the main microsites. These were bare peat (n=3)*, Juncus effusus-Sphagnum cuspidatum* (n=3)*, Sphagnum cuspidatum* (n=3) and *Eriophorum angustifolium* dominated communities (n=3).

CO_2 flux measurements

CO_2 fluxes were measured from Nov 2008 to Dec 2011 at biweekly (summer months) to monthly (winter months) intervals using the static chamber method (Alm *et al.* 1997). Instantaneous net ecosystem exchange (NEE) was measured over a range of PPFD ($\mu mol\ m^{-2}\ s^{-1}$) values using a transparent polycarbonate chamber (60 x 60 x 33cm) and a portable CO_2 analyser (EGM-4) (PP Systems. UK). Soil temperatures (5, 10 and 20cm depths) were recorded at each collar with a soil temperature probe and WT position relative to the soil surface was manually measured with a water level probe. Following each NEE measurement, the chamber was then replaced in the collar and covered with an opaque material in order to provide an estimate of ecosystem respiration (R_{ECO}). CO_2 flux rates ($mg\ m^{-2}\ h^{-1}$) were calculated from the linear change in CO_2 concentration in the chamber headspace over time with respect to the chamber volume and temperature. We use the ecological flux sign convention whereby positive fluxes indicate a net uptake of CO_2 by the ecosystem. An estimate of gross photosynthesis (P_G) was calculated as the sum of NEE and R_{ECO} values (Alm *et al.* 1997).

CO_2 flux modelling

P_G is strongly dependent on irradiation (PPFD) and is a commonly described by the Michaelis-Menten function showing a hyperbolic response approaching an asymptotic maximum. The seasonal variation in the photosynthetic capacity of the vegetation is described by GAI and incorporated into the model in a manner similar to Wilson *et al.* (2007) (Eq.1, 2 and 3).

$$P_G = P_{\max}\left(\frac{PPFD}{PPFD+k_{PPFD}}\right) * GAI * \left[exp\left(-0.5\left(\frac{WT-a}{b}\right)^2\right)\right] \qquad \textbf{(Eq.1)}$$

$$P_G = P_{\max}\left(\frac{PPFD}{PPFD+k_{PPFD}}\right) * GAI \qquad \textbf{(Eq.2)}$$

$$P_G = P_{\max}\left(\frac{PPFD}{PPFD+k_{PPFD}}\right) * \left[\frac{GAI}{(GAI + c)}\right] \qquad \textbf{(Eq.3)}$$

where P_G is gross photosynthesis, P_{max} is maximum photosynthesis, PPFD is photosynthetic photon flux density, k_{PPFD} is the PPFD value at which P_G reaches half its maximum, GAI is green area index, WT is water table depth, *a*, *b* and c are model parameters.

Ecosystem respiration (R_{ECO})
In the R_{ECO} model we used temperature and WT as explanatory variables (Riutta *et al.* 2007)

$$R_{ECO} = a^* exp^* \left[b\left(\frac{1}{T_{REF}-T_0} - \frac{1}{T-T_0}\right)\right] * \left[\frac{1}{1+\exp(\frac{WT-c}{d})}\right] \qquad \textbf{(Eq.4)}$$

where R_{ECO} is ecosystem respiration, T_{REF} is reference temperature set at 283.15 K, parameter T_0 is the temperature minimum at which respiration reaches zero, WT is water table depth, *a*, *b* and *c* are model parameters.

P_G and R_{ECO} were parameterised separately for each microsite. Model coefficients were estimated using the Levenberg-Marquardt multiple non-linear regression technique (PASW Statistics 18, SPSS Inc. Chicago. USA).

Reconstruction of annual CO_2–C balance

The response functions estimated for P_G and R_{ECO} were used for the annual reconstruction of NEE. In combination with an hourly time series of (1) PPFD and T_{5cm}, recorded by the weather station and data loggers, (2) modelled GAI and (3) WT depths linearly interpolated from weekly measurements, P_G and R_{ECO} fluxes were reconstructed for each sample plot. NEE was then calculated on an hourly basis as follows: NEE = $P_G - R_{ECO}$ (Alm *et al.* 1997). The annual CO_2–C balance (g C m^{-2} yr^{-1}) was calculated for each sample plot by integrating the hourly NEE values over 12-month periods (January 1st to December 31st 2009, 2010 and 2011). An average value (± standard deviation) for each microsite was calculated from the annual CO_2-C balance of the sample plots within the microsite.

RESULTS

Photosynthetic photon flux density (PPFD) was similar over the three years of the study (Fig. 1). Annual rainfall was 1326mm in 2009, 1125mm in 2010 and 1376mm in 2011 (Met Éireann, Belmullet Station). This represented a deviation from the long-term average value by +16, -1.6 and +20% respectively. In 2010, relatively low rainfall in the spring and early summer (Fig. 1) resulted in a significant drawdown in the water table level at all the microsites (Table 1).

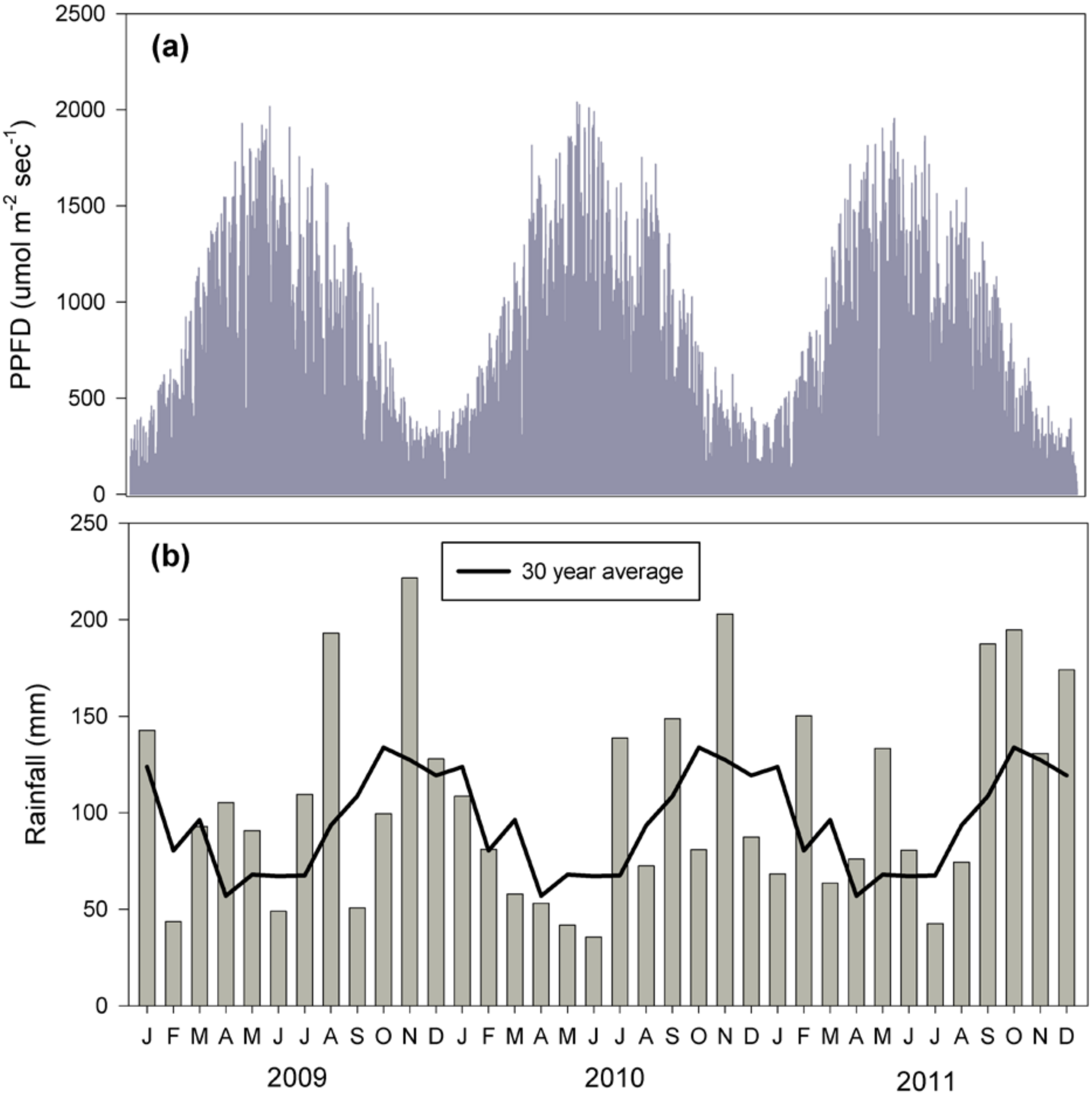

Figure 1. Climatic data for Bellacoric C. Mayo in 2009, 2010 and 2011 (a) Photosynthetic Photon Flux Density (PPFD, umol m^{-2} s^{-1}) and (b) monthly rainfall (mm) (Met Éireann-Belmullet Station).

Table 1. Annual NEE (g CO_2-C m.$^{-2}$ yr^{-1}) ± SD in parentheses for the microsites at Bellacorick for 2009, 2010 and 2011. Positive NEE values indicate a net CO_2-C uptake by the peatland. Mean annual water table (WT, cm), min and max WT shown in parentheses. Positive WT values indicate a WT level above the soil surface.

Year	**2009**		**2010**		**2011**	
Microsite	**WT**	**NEE**	**WT**	**NEE**	**WT**	**NEE**
Bare peat	-0.4 (-19 to +5)	-46.7 (5.40)	-3.9 (-40 to +5)	-81.6 (20.7)	-0.4 (-5 to +2)	-37.3 (3.60)
Juncus-Sphagnum	+5.6 (-4 to 10.5)	142.8 (8.80)	+3.5 (-29 to 8.5)	43.1 (38.80)	+7.1 (+4.5 to +9.5)	211.2 (46.30)
Sphagnum	+12.5 (+8 to +16)	106.8 (3.6)	+9.5 (-11 to +14.5)	47.4 (50.2)	+13.2 (+9 to +21)	144.7 (71.3)
Eriophorum	+6.3 (-9 to +14)	587.9 (160.7)	+6.0 (-18 to +20)	150.93 (86.9)	+7.4 (+2 to +14)	305.0 (89.1)

All the vegetated microsites were significant sinks for CO_2 over the three years of the study but showed strong variation both spatially and temporally. The highest uptake took place in the *Eriophorum* dominated community in each year (150.9 to 587.9 g CO_2-C m^{-2} yr^{-1}), driven by high P_G in those plots (data not shown). Annual CO_2 uptake was lower in the *Juncus-Sphagnum* (43.1 to 211.2 g CO_2-C m^{-2} yr^{-1}) and *Sphagnum* (47.4 to 144.7 g CO_2-C m^{-2} yr^{-1}) dominated microsites. Inter-annual variation was a strong feature in all microsites and was driven by differences in GAI, WT depth and soil temperature. The unvegetated bare peat plots were a net CO_2 source in each year of the study, with the highest emissions (81.6 g CO_2 m^{-2} yr^{-1}) occurring in 2010.

DISCUSSION

The NEE results presented here are at the upper range of reported values for rewetted peatlands (Tuittila *et al.* 1999, Yli-Petäys *et al.* 2007, Kivimäki *et al.* 2008). Given the successional stage of the peatland, biomass and litter are still increasing rapidly but over time will reach steady state equilibrium in terms of the rate of C sequestration. After that, the accumulation of organic matter (and the C therein) in a new peat layer is typically much slower (Lucchese *et al.* 2010). Furthermore, under a mild temperate climate, the growing season is considerably longer than in boreal climates, providing an extended timeframe for CO_2 uptake. Combined with the wide coverage of evergreen moss species, such as *Sphagnum cuspidatum*, at the study site, photosynthetic activity and hence CO_2 uptake may take place even during the winter months. In addition, the high C:N ratio recorded at the site indicates that the residual peat at Bellacorick is nutrient poor and may result in lower microbial decomposition rates, and therefore, lower CO_2 production (Francez *et al.* 2000).

Climate modelling exercises have predicted that precipitation distribution and frequency will change in Ireland over the coming decades (Sweeney *et al.* 2008) and that areas, such as North West Mayo will experience increased rainfall during the summer months. During the period of the study, the years 2011 and 2009 were the 7th and 8th wettest years since 1957 and undoubtedly contributed to the high water tables observed at the study site.

The potential for rewetted peatlands as a climate mitigation option has been widely discussed in recent years (Parish *et al.* 2008, Joosten and Couwenberg 2009). The use of restored peatlands for C offset projects is attractive in that they offer the prospective for C mitigation by (a) transforming an ecosystem that is a large C source (e.g. an industrial peatland) to one in which the C losses are reduced (avoided losses), and (b) increasing the amount of C that may be actively sequestered by the peatland.

CONCLUSION

The results presented here suggest that the rewetting actions and subsequent re-colonisation of the highly degraded peatland at Bellacorick have been successful in creating suitable conditions for CO_2 sequestration. Combined with increased precipitation in the coming decades rewetted peatlands, such as Bellacorick, may become “prime real estate” for climate change mitigation, although the resumption of methane emissions following rewetting will also have to be taken into account.

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