Ecosystem scale CO_2 fluxes in a blanket peatland: How well do we need to know the landscape system?

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Introduction

Blanket bogs are often characterised by an undulating pattern of microforms, namely: hummocks, lawns and hollows. Microforms differ from each other in terms of water table level, plant composition and peat pH (Doyle 1982). In raised bogs these differences cause small-scale spatial variation in carbon dioxide (CO_2) dynamics (Alm et al. 1997). In blanket bogs the structural and functional differentiation between microforms is reflected in the spatial variation in carbon accumulation rate (Tallis 1994).
The two main approaches used to measure CO_2 gas exchange in peatlands are the chamber and eddy covariance (EC) techniques. Both of these have advantages and disadvantages when used to determine ecosystem CO_2 balance. In this study we consider ways of comparing these two methods.

Objectives

Our overall goal was to determine the level of knowledge required about the spatial variation in a heterogeneous peatland ecosystem to enable ecological interpretation of CO_2 dynamics. More specifically, we aim to quantify the possible bias associated with tower measurements in a heterogeneous ecosystem, where microform distribution may differ between the prevailing wind direction within the EC tower footprint and the whole peatland complex. In pursuance of this we compared two postulates: (1) the microform distribution in the footprint is sufficiently homogenous so that with a moving footprint we get a representative estimate of CO_2 balance over a certain period of time or, (2) in order to get a reliable estimate of net ecosystem CO_2 exchange for blanket peatland, the distribution of microforms inside the instantaneous footprint must be known.

Site description

The study was conducted over a four-month period (July 1 to October 31, 2003) at an Atlantic blanket peatland situated at 150 m asl. in Dromalonhurt, Co. Kerry, Ireland (51°.55´N, 9°.55´W) (Fig. 1). The mean annual precipitation in the area is 1430 mm, average temperature in the warmest month (July) 14.8 ºC and in the coldest month (February) 6.6 ºC (30 years averages from the Valentia weather station, ~30 km west from Dromalonhurt).
The surface of the study site is a mosaic of microforms, which we divided into four classes: hummocks (*HU*), high lawns (*HL*), low lawns (*LL*) and hollows (*HO*) (Fig. 2).

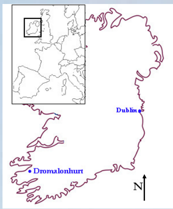

Figure 1. Location of study site

Methods

• Chamber measurements

Six collars (0.6*0.6*0.15 m) were inserted into the peat around *HU*, *HL* and *LL*, respectively. A closed chamber technique, with a vented and thermostatically controlled transparent plastic chamber (0.6*0.6*0.33 m) was used; CO_2 concentration inside the chamber was monitored with a portable infrared gas analyser (EGM-4, PP Systems, UK). The instantaneous net CO_2 exchange (*NEE*) was measured in stable ambient illumination at 15-second intervals over a 60-240 seconds period. Immediately following this total respiration (R_{TOT}) was estimated by measuring *NEE* while the chamber was covered with an opaque lid.
In order to relate the gas fluxes to prevailing environmental conditions, the photosynthetic photon flux density (*PPFD*) and air temperature inside the chamber were measured simultaneously with CO_2 concentration. Soil temperatures at 5, 10, 20 and 30 cm depths and water table depth (*WT*), relative to the sample plot surface, were also recorded.

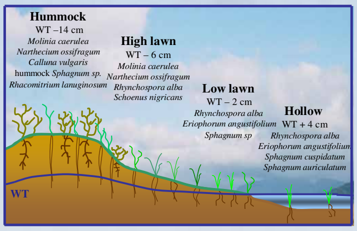

Figure 2. Schematic representation of microforms. Mean water table level over the 4 month period and dominant vegetation.

Figure 3. The chamber system used in measurements

• Modelling of CO_2 exchange fluxes

Individual process based models were created and parameterised for each microform to describe gross photosynthesis (P_G) and R_{TOT}. P_G was calculated as the sum of *NEE* and R_{TOT}. CO_2 fluxes of *HO* were estimated using models created for *LL*.
NEE was calculated at 30 minute intervals for each microform: $NEE = P_G - R_{TOT}$. Microform level *NEE* values were upscaled to ecosystem level in two ways: (1) the half hourly *NEE* estimates of each microform were weighted by the average microform distribution within the peatland (Ecosystem 1), and (2) the *NEE* of each microform was weighted according to the microform distribution in the prevailing wind direction for each half hour (Ecosystem 2). These NEE values were integrated over the four-month period.
The range of *NEE* in different wind directions was estimated as follows. The *NEE* of the two most different transects were compared to the average peatland microform distribution. *NEE* was weighted by the microform distribution of the wettest (NNW) and the driest (E) transects (Fig. 7). This was performed to quantify the maximum bias that the instantaneous footprint can cause, in comparison with the use of the whole peatland ecosystem *NEE* estimation.

P_G model for *HU* and *HL*:
$$P_G = Q^* \, PPFD / (k + PPFD)$$

P_G model for *LL*:
$$P_G = Q^* \, PPFD / (k + PPFD)^* V$$

R_{TOT} model for *HU* and *HL*:
$$R_{TOT} = b^* \exp(b_1{}^* T_{20}) + (b_2{}^* WT)$$

R_{TOT} model for *LL*:
$$R_{TOT} = b^* \exp(-b_1{}^* WT)$$

Where *PPFD* is photosynthetically active photon flux density, *V* is the cover of vascular plants (%), T_{20} is soil temperature in 20 cm depth and *WT* is water table.

• Eddy-covariance measurements

Figure 4. 3D Sonic anemometer and open-path CO_2/H_2O gas analyser

The eddy covariance system consisted of a 3-D sonic anemometer (81000, R.M. Young Company, USA) and an open-path CO_2/H_2O gas analyser (LI-7500, LI-COR, USA) mounted at 3 m above the ground surface (Fig. 4). Data were recorded on a data logger at a frequency of 10 Hz and were Reynolds-averaged every 30 minutes.

Micrometeorological observation equipment included:
- a net radiometer;
- a photosynthetic photon flux density sensor;
- a barometric pressure sensor;
- an air temperature and relative humidity probe;
- soil temperature probes at 20, 40, 60 and 100 cm depths;
- a tipping bucket rain gauge

Signals from all the micrometeorological sensors were monitored every minute and averaged over a 30 minutes period. Precipitation data were summed over the same time interval.

Figure 5. EC Tower

The EC CO_2 flux data were corrected for variations in air density due to fluctuation in water vapour and heat flux (Webb et al. 1980). 20 W m^{-2} of short-wave incoming radiation was considered as threshold dividing day by night records. The data were then filtered for malfunctions of the gas analyser and sonic anemometer. Good data were defined as:

	Day data filter	Night data filter
July-October:	No precipitation + 1 hr after rain event	
		$u_* > 0.15$ m s^{-1}
July-August	$-2 < NEE < 15$ µmol m^{-2} s^{-1}	$-10 < NEE < 0$ µmol m^{-2} s^{-1}
September-October	$-2 < NEE < 12$ µmol m^{-2} s^{-1}	$-8 < NEE < 0$ µmol m^{-2} s^{-1}

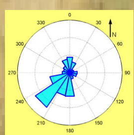

Figure 6. Wind rose

Daytime gaps were filled by rational equations describing the relationship between *PPFD* and good *NEE* values. A separate relationship was computed for each month. Night time data gaps were filled using a single Q_{10} function (with 10ºC as reference) explaining the relationship between *NEE* and soil temperature at 20 cm depth. A single relationship was computed for all four months together.

• Sign convention

The ecological sign convention, in which fluxes from the biosphere to the atmosphere are negative, was used in this study.

• Microform distribution

The microform distribution was surveyed along 16 radial transects at 22.5° intervals around the EC tower. The proportion of each microform type was assessed along each transect at 5 m intervals. The transect length was 50 m, except for the prevailing wind directions (see Fig. 6), where the transect length was 200m (in the WSW and SSW directions) and 300 m (in the SW direction).

Results and discussion

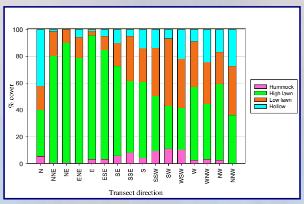

Figure 7. Microform distribution along the transects around EC tower

The average distribution of microforms was 4, 58, 25 and 13 % in *HU, HL, LL* and *HO*, respectively. Drier microforms, *HU* and *HL*, dominated most transects (Fig. 7), while five transects had a higher proportion of wetter microforms (*LL* and *HO*). *HU* were the least common of all microforms.

Measured *NEE* showed both spatial and temporal variation within the bog. *HU* had on average higher positive (photosynthesis) and negative (respiration) fluxes than other microforms (Fig. 8). Fluxes were highest during August and decreased noticeably in October. *NEE*, measured by the EC tower varied within same range as chamber measurements.

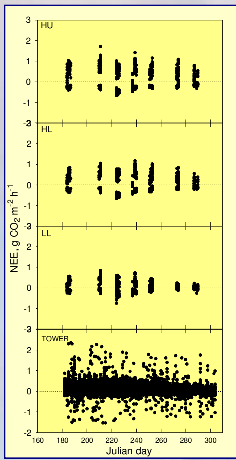

Figure 8. Measured *NEE* in microforms *HU, HL, LL* and *NEE* measured by tower

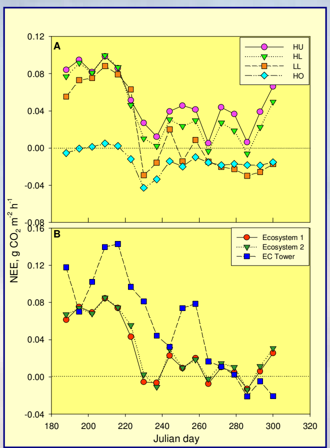

Figure 9. Modelled weekly average *NEE* flux in A) microforms and B) upscaled to ecosystem level by using the average microform distribution (Ecosystem 1) and using the wind direction determined microform distribution (Ecosystem 2) and calculated from EC tower fluxes

Microforms supported different weekly average *NEE* (Fig. 9A). In drier microforms *NEE* was positive during the whole study period, while wetter microforms, especially *HO*, were a source of CO_2 most of the time.
The two different approaches to upscale *NEE* from microforms to the ecosystem level gave similar results (Fig 9B). CO_2 uptake was highest in July, decreased in August and remained relatively small for the rest of the study period.
The EC method estimated higher CO_2 uptake in the middle of the study period and lower at the end.

As already highlighted (Fig. 9B) the two different approaches used to upscale *NEE* from microform to ecosystem level gave very similar results on a monthly basis (Fig. 10). This indicates that wind direction did not have a great impact on the result. The four month CO_2 balance based on the microform distribution of wettest and driest transect was 41 % lower and and 42 % higher, respectively, than the result obtained using the average microform distribution (Fig.10).
Comparison of chamber and EC measurements is complicated, since in some months EC technique gives higher and some months lower CO_2 balances than the chamber method based calculations. The total 4-month CO_2 balance for both methods is similar.

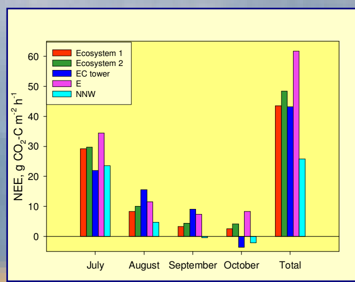

Figure 10. Monthly *NEE* based on upscaling from chamber measurements Ecosystem 1 (average microform distribution) and Ecosystem 2 (wind direction determined microform distribution) and based on EC tower measurements. *NEE* weighted by the microform distribution of the two most different transects, driest transect E and wettest transect NNW.

Conclusions

- Similarly to raised bogs, microforms in blanket bogs support different CO_2 dynamics (Fig. 9A).
- Wind direction did not have a strong influence on *NEE* (Figs. 9B and 10). Although, if the microform distribution in the dominant wind direction would have differed strongly from the average, the *NEE* from the EC method could have been very different from the actual situation, as can be seen from the NEE values of the very dry or wet transects, which were around ±40 % higher or lower, respectively, than the average.
- The study supported the postulate that the microform distribution in the footprint is sufficiently homogenous so that with a moving footprint we get a representative estimate of CO_2 balance over a certain period of time.

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