Extended abstract No. 272

NET ECOSYSTEM CARBON DIOXIDE EXCHANGE AT SEMI-NATURAL AND REGENERATING TEMPERATE FENS

Ross Morrison. Department of Geography, Bennett Building, University of Leicester, University Road, Leicester. LE1 7RH. Telephone: +44(0)116 252 3843 Email: rdm11@alumni.le.ac.uk

Jon Kelvin (Centre for Ecology and Hydrology (CEH), Wallingford), Peter Stroh (Anglia Ruskin University (ARU)), Susan E. Page (University of Leicester (UoL)), Francine Hughes (ARU), Jörg Kaduk (UoL), Mike Acreman (CEH, Wallingford) Richard Harding (CEH, Wallingford) & Heiko Balzter (UoL)

SUMMARY

Net ecosystem CO_2 exchange was measured at two managed fens in the East Anglian Fenland region of the East of England (United Kingdom). Eddy covariance measurements were made at a semi-natural fen and a regenerating former arable fen at the Wicken Fen Nature Reserve. Both ecosystems were characterised by significant seasonal variation in gross primary production, ecosystem respiration and net ecosystem CO_2 exchange. The semi-natural site was a net source of CO_2 between late March and December 2009 and a net sink during the same period the following year. The regenerating site was a small net source of CO_2 on an annual basis.

KEY WORDS: Managed fens, restoration, net ecosystem exchange, carbon dioxide, eddy covariance

INTRODUCTION

Peatlands are wetlands that store a disproportionate amount of soil carbon (C) relative to other terrestrial ecosystems. The long-term stability of peatland C stocks is of major concern as small changes in C fluxes to and from this pool have the potential to significantly influence atmospheric C loading (Baird et al., 2009). Fens are minerotrophic peatlands of high conservation status. In Europe and elsewhere, large areas of fen peatland have been drained and converted for intensive arable land use (Thompson, 2008). Agricultural use of peatlands is associated with large-scale transfers of historically accumulated soil C to the atmosphere as carbon dioxide (Veenendaal et al., 2007). Landscape-scale fenland restoration has the potential to reduce or reverse carbon dioxide (CO_2) loss relative to arable fens and has been cited as an option for mitigating land use related CO_2 emissions (Thompson, 2008). Despite this, C cycle processes in managed fens have been poorly quantified and the magnitude of any CO_2 savings resulting from restoration remains uncertain (Baird et al., 2009). Furthermore, the ability to protect or enhance remaining fenland soil C stocks in a changing climate requires improved knowledge of the dynamic response of CO_2 exchange to environmental variability.

The East Anglian Fenland (The Fens) of the East of England contains the largest expanse of lowland fen peat in England. Widespread drainage and agricultural intensification has resulted in significant habitat and soil C loss. Only four fragments of semi-natural (undrained) fen remain in the region. Concerns over the future of fenland biodiversity and soil carbon are driving efforts to expand existing nature reserves by rewetting large tracts of agriculturally degraded fenland (Stroh et al., 2010). Here, we present eddy covariance (EC) measurements of net ecosystem CO_2 exchange (NEE) obtained at a semi-natural (undrained) reference site during two hydrologically dissimilar periods, and at an adjacent area of regenerating former arable peatland over a complete annual cycle. Our objectives are to (i) present CO_2 budgets for the two fens, (ii) analyse between year differences at the semi-natural reference site, and (iii) contrast CO_2 exchange at the two fen ecosystems.

MATERIAL AND METHODS

The study sites are located at the Wicken Fen Nature Reserve in the Cambridgeshire Fens (52˚18'N, 0˚16'E, 1.7 m OAD). The climate of the region is temperate, mean annual temperature is 9.8°C and average yearly precipitation is 533 mm. The semi-natural Wicken Sedge Fen (WSF) site is dominated by *Phragmites australis* and *Cladium mariscus*. Soils are Adventurers series fen peats approximately 2 m in depth. Vegetation management consists of small-scale rotational cutting. The regenerating Bakers Fen (BF) site was drained in the mid-nineteenth century and used for intensive arable production prior to restoration. Restoration commenced in 1994 and consists of winter (November to March) abstractions of calcareous water from a local watercourse and low density grazing. Extensive peat wastage (circa 1.5 m) has occurred across the site and residual peat depth is approximately 0.6 m. Vegetation has developed towards a species composition characteristic of wet fen meadow. Distance between the sites is approximately 1 km. Measurements were made between April and December in 2009 and 2010 at WSF, and over the complete annual cycle of 2010 at BF.

The EC system at WSF consists of a GILL Instruments R3 sonic anemometer and LI-COR Li7500 infrared gas analyser. The instrumentation at BF comprises a Campbell Scientific CSAT3 sonic anemometer and LI-COR Li7500. A suite of environmental measurements including: net radiation and soil heat flux, photosynthetically active radiation, precipitation and water levels, and air temperature and relative humidity were made at both sites using identical sensors. Fluxes were computed over thirty minute intervals using standard processing methods (Mauder et al, 2008). Quality control, data gap-filling and flux partitioning were conducted using standardised methods (Reichstein et al., 2005; Papale et al., 2006). Uncertainty in time-integrated NEE was assessed using methods similar to Elbers et al. (2011). Energy balance closure was 84% and 76% at WSF and BF, respectively.

RESULTS

Strong seasonal and between year variations in environmental conditions were observed during the study period (Fig. 1). Conditions in 2009 were warmer than average whilst 2010 was cooler. 2009 was drier than average and 2010 was close to the long-term mean. Spring and October 2009 were warmer than average, whereas 2010 was characterised by a delayed start of the thermal growing season and early onset of winter conditions. August was the warmest month in 2009; July 2010 was the warmest month of the measurement period. Temperatures were colder than normal during all winter months. Both years experienced drier than normal spring conditions. July was the wettest summer month in 2009 and the driest in 2010. August 2010 was the wettest in over three decades. Conditions were dry during early autumn in 2009. Water levels at WSF fell steadily during spring and early summer in both years. Dry conditions in late summer and early autumn 2009 led to maximum water level drawdown in October. In 2010, the extremely high August rainfall resulted in higher late season water levels than the previous year. Water levels at BF were below the mean peat surface at the start of the measurement period. Groundwater levels fell rapidly during spring and the water table was close to the peat base during the summer months (despite high August rainfall). No water was abstracted onto BF in late 2010 and water level recovery reflected the shift to a positive water balance.

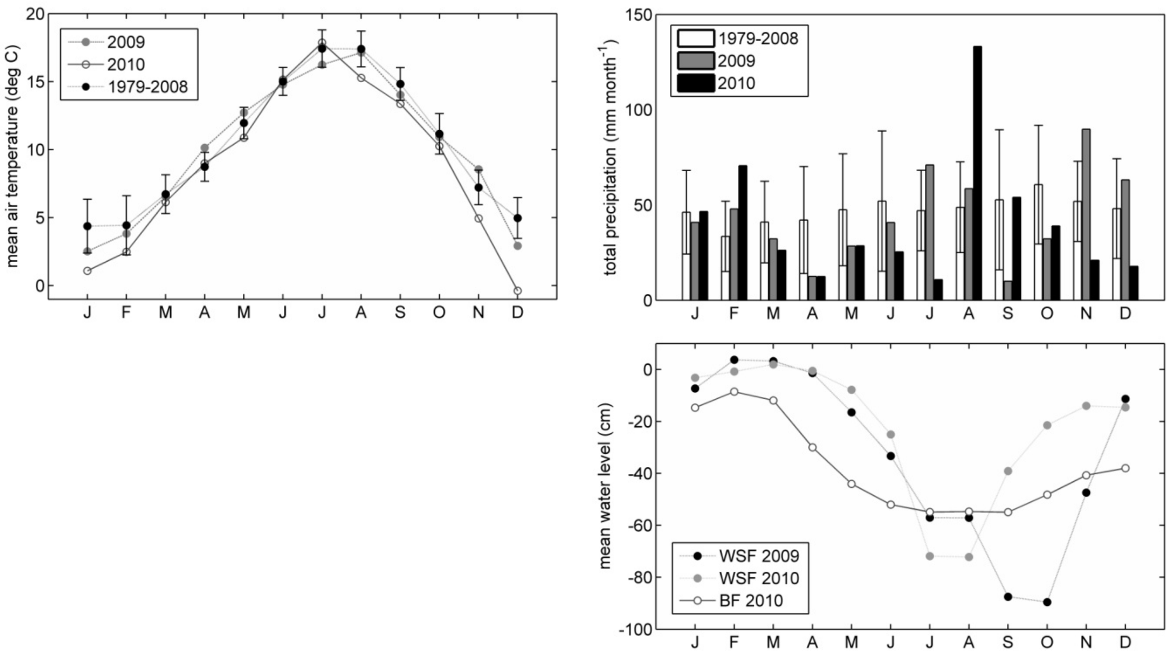

Fig 1. Monthly values of key environmental variables measured at Wicken Fen during 2009 and 2010. 1979 to 2008 data provided by the Met Office.

Both sites were characterised by significant seasonal variation in gross primary production (GPP), ecosystem respiration (ER) and NEE (Fig. 2). At WSF (Fig 2. left), GPP and ER were higher during all months of 2009 than in 2010, with the exception of July when highest monthly GPP and ER were observed for the measurement period. Net CO_2 uptake occurred between April and July in both years with the highest net uptake in June 2009. CO_2 uptake was greater during spring and early summer of 2009 than in 2010. The site functioned as a net CO_2 source between August and December in both years. Significantly higher ER was observed during the interval between September and December 2009 than for the corresponding period of 2010. Temperature and water levels were both found to be important controls on ER at this peatland site (not shown). Total GPP and ER summed over the measurement period were both higher in 2009 than in 2010. GPP was estimated at 1571.9 g C m^{-2} and 1438.3 g C m^{-2} in 2009 and 2010, respectively. In 2009, ER was 1653.5 g C m^{-2} in 2009 and 1410.5 g C m^{-2} in 2010. The site was a net source of +81.6±21 g C m^{-2} between April and December in 2009 and a net sink of -27.74±19 g C m^{-2} during 2010, a net difference of 109.3 g C m^{-2}.

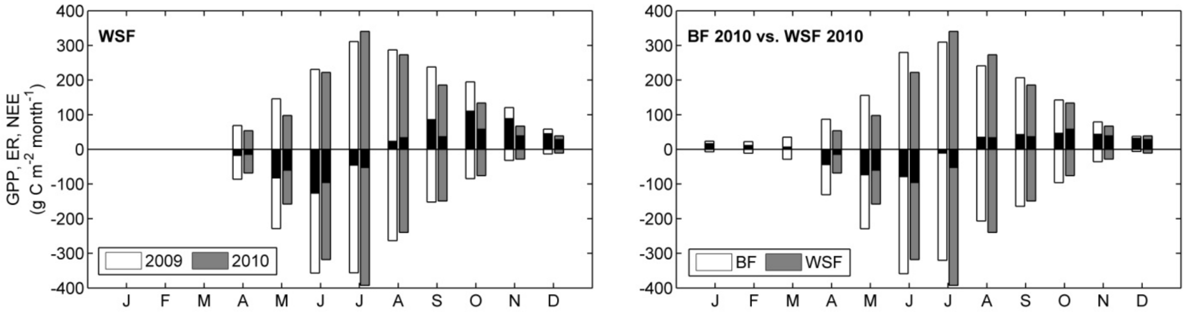

Fig 2. Monthly GPP, ER and NEE measured at WSF in 2009 and 2010 (left) and at WSF and BF during 2010 (right). Negative (white and grey) bars show GPP; ER is shown by positive bars. Black bars show NEE (negative values indicate net CO_2 uptake).

The BF site was a small net source of+26.4±13.7 g C m^{-2} a^{-1} in 2010. Annual GPP was estimated at 1617.1 g C m^{-2} y^{-1}, losses via ER totalled 1643.5 g C m^{-2} a^{-1}. Total monthly GPP was highest in June, whilst monthly ER reached a maximum in July (Fig 2; right). Lowest monthly GPP and ER were observed in January. GPP and ER were higher at BF than WSF during all growing season months excluding July and August. Similar to WSF, BF was a net sink for atmospheric CO_2 between April and July, and a source during all other months. Net CO_2 uptake was higher at BF in April and May, but lower than WSF in June and July. Net CO_2 loss was of similar magnitude between August and December at both sites. Total NEE for the period when both towers were operational was estimated at -8.06 g C m^{-2}, of which 1567.6 g C m^{-2} and 1559.5 g C m^{-2} were attributed to GPP and ER, correspondingly. The difference in time-integrated NEE between the WSF and BF sites was 19.7 g C m^{-2} for this interval (WSF being the larger sink). GPP and ER were both higher at BF, with differences of 129.4 and 158 g C m^{-2}, respectively.

DISCUSSION AND CONCLUSIONS

We have presented CO_2 budgets for two managed fens in the East Anglian Fens. To the best of our knowledge, these results represent two of only three micrometeorological studies of CO_2 exchange at any type of lowland fen peatland in the UK (Evans *et al.* 2011). The semi-natural site was a net source of atmospheric CO_2 during warm and dry conditions in 2009 and a net sink in the same period in 2010. Both GPP and ER were enhanced during the warm year, but the increase in spring photosynthesis did not compensate for higher rates of ER in autumn. ER showed strong relationship with water levels at this site, indicating that the higher ER in autumn 2009 was due to enhanced oxidation of aerated peat. We did not measure winter fluxes at WSF. As WSF was close to CO_2 neutrality during the measurement period of 2010, it is likely that CO_2 loss between January and March would render the site a net source of atmospheric CO_2 (and a larger CO_2 source in 2009). We note that the high water levels in autumn 2010 were the result of extreme summer rainfall. Lower late summer water levels and higher ER rates are likely to better reflect conditions at WSF. This underlines the need to for improved management of water levels at this semi-natural fen.

The CO_2 budget for the regenerating BF site appears to be the only available estimate for a fen that has been restored after intensive arable land use (Baird et al., 2009). The BF site was close to CO_2 neutral on an annual basis despite the absence of high water levels during summer months. It is likely that CO_2 losses are low from the highly recalcitrant peat at the site, and possible that improved hydrological management could render the site a net sink for atmospheric CO_2. In the UK, CO_2 emissions from agricultural fens with peat of less than 1 m currently are reported as 109 g C m^{-2} a^{-1} (Thompson, 2008). On the basis of this and our annual estimate, we calculate a net CO_2 emissions reduction of 68.9 to 96.3 g C m^{-2} a^{-1} (252.9 to 353.46 g CO_2 m^{-2} a^{-1}). We stress that our measurements were obtained over a single year that was cooler than long-term conditions for the region. The significant difference in NEE observed at the semi-natural site highlights the need for longer-term monitoring of these managed ecosystems.

ACKNOWLEDGEMENTS

Ross Morrison acknowledges financial support from the University of Leicester and the Centre for Ecology and Hydrology. We thank the British National Trust and staff of the Wicken Fen Reserve, We are grateful to all those who assisted during fieldwork.

REFERENCES

Baird, A., Holden, J. and Chapman, P. (2009). *A Literature Review of Evidence on Emissions of Methane in Peatlands*. Defra Project SP0574.

Elbers, J. A., Jacobs, C. M. J., Kruijt, B., Jans, W. W. P., and Moors, E. J. (2011). Assessing the uncertainty of estimated annual totals of net ecosystem productivity: A practical approach applied to a mid latitude temperate pine forest. *Agricultural and Forest Meteorology*, **151**, 1823-1830

Evans, C., Worrell, F., Holden, J., Chapman, P., Smith, P. and Artz, R. 2011. *A programme to address evidence gaps in greenhouse gas and carbon fluxes from UK peatlands*. JNCC Report No. 443

Mauder, M., Foken, T., Clement, R., Elbers, J.A., Eugster, W., Grunwald, T., Heusinkveld, B. and Kolle, O. (2008). Quality Control of CarboEurope flux data - Part 2: Inter-comparison of eddy-covariance software. *Biogeosciences*, **5**, 451-462.

Papale, D., Reichstein, M., Aubinet, M., Canfora, E., Bernhofer, C., Kutsch, W., Longdoz, B., Rambal, S., Valentini, R., Vesala, T. and Yakir, D. (2006). Towards a standardized processing of Net Ecosystem Exchange measured with the eddy covariance technique: algorithms and uncertainty estimation. *Biogeosciences*, **3**, 571-583.

Reichstein, M., Falge, E., Baldocchi, D., Papale, D., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Gilmanov, T., Granier, A., Grünwald, T., Havránková, K., Ilvesniemi, H., Janous, D., Knohl, A., Laurila, T., Lohila, A., Loustau, D., Matteucci, G., Meyers, T., Miglietta, F., Ourcival, J.-M., Pumpanen, J., Rambal, S., Rotenberg, E., Sanz, M., Tenhunen, J., Seufert, G., Vaccari, F., Vesala, T., Yakir, D. and Valentini, R. (2005). On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm. *Global Change Biology*, **11**, 1424-1439

Stroh, P. A., Hughes, F. M.R., Sparks, T. H., and Mountford, J. O (2011). The influence of time on the soil seed bank and vegetation across a landscape-scale wetland restoration project. *Restoration Ecology*. **20**, 103-112

Thompson, D. (2008). *Carbon Management by Land and Marine Managers*. Natural England Research Reports, Number 026.

Veenendaal, E.M., Kolle, O., Leffelaar, P.A., Schrier-Uijl, A.P., Van Huissteden, J., Van Walsem, J., Moller, F. and Berendse, F. (2007). CO_2 exchange and Carbon balance in two grassland sites on eutrophic drained peat soils, *Biogeosciences*, **4**, 1027–1040.