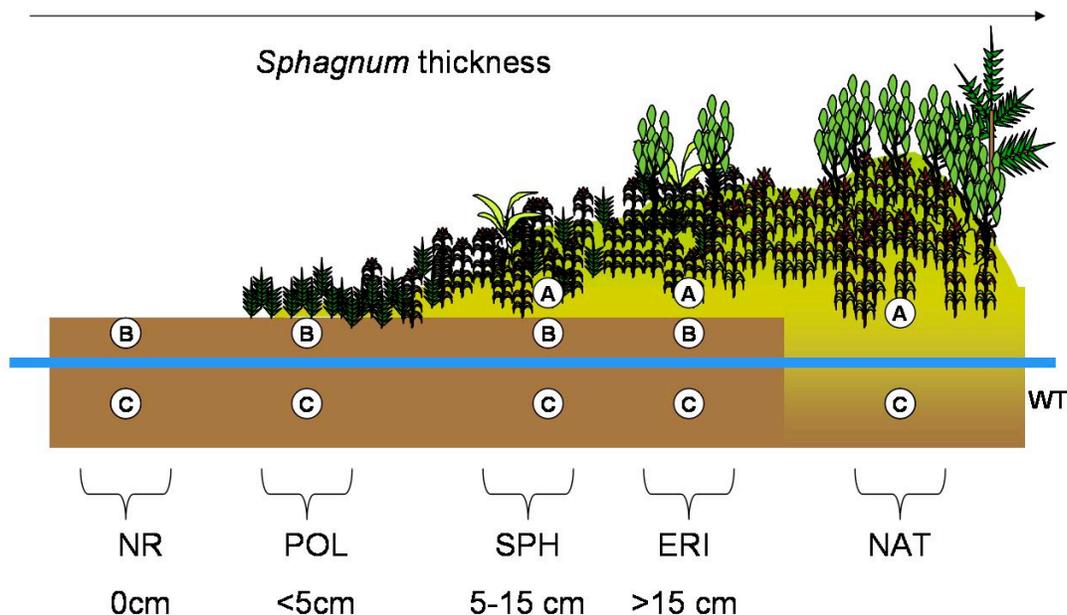


# Restoring the Carbon Accumulation Function in Cutover Bogs: do Micro-organisms Matter?

Andersen, Roxane\*<sup>1,3</sup>; Pouliot, Remy<sup>1</sup>; Rochefort, Line<sup>1</sup>; Francez, Andre-Jean<sup>2</sup> and Rebekka Artz<sup>3</sup>

<sup>1</sup>Universite Laval, Quebec, Canada, G1V 0A6. ([r.andersen@macaulay.ac.uk](mailto:r.andersen@macaulay.ac.uk)); <sup>2</sup>Université de Rennes 1, Campus de Beaulieu, F-35042 Rennes cedex ; <sup>3</sup>The Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB15 8QH

North American peatlands harvested for horticultural purposes remain dysfunctional when exploitation ceases, and need to be restored or reclaimed (Rochefort et al., 2003). The “*Sphagnum* moss transfer” technique has been developed for large scale restoration of cutover bogs, with the long term objective of bringing back these ecosystems to a functional state. From this perspective, restoration could only be considered a success if remains of new *Sphagnum* reached the catotelm without being decomposed totally in the acrotelm. Microbial recovery is delayed in comparison with vegetation establishment following restoration (Anderson et al., 2006) but as plants accumulate, fresh organic matter inputs might stimulate decomposition by micro-organisms (Glatzel et al. 2004) and compromise peat accumulation. We determined how surface vegetation and environmental conditions interact with the structure and activity of microbial communities in a gradient of increasing *Sphagnum* thicknesses found in cutover, restored and natural peatlands. We evaluated phospholipid fatty acid composition (PLFAs), decomposition potential, actual decomposition rates and we are currently assessing genetic diversity.



Schematic representation of 5 classes of *Sphagnum* thicknesses where microbiology was monitored. Classes :Non-restored bare peat (NR), *Polytrichum strictum* carpets (POL), *Sphagnum* spp. carpets (SPH), Ericaceous shrubs (ERI) and Natural communities (NAT). Three types of samples /class:: A: new peat, aerobic conditions; B, old peat, aerobic conditions; and C old peat anaerobic conditions.

Our results suggest that the newly formed peat found in aerobic conditions beneath *Sphagnum* carpets has the highest decomposition potential, whereas the lowest potential is found in the surface samples of disturbed conditions and in the deepest horizons of the natural samples. The vegetation cover, the physicochemical environment and the microbial structure of the community all contribute to explain differences in decomposition potential. Overall, this study reveals that the recovery of mosses and shrubs in restored peatlands might be the driver of changes occurring in the belowground microbial communities – and that decomposition might be the limiting factor in the recovery of the peat accumulation function in restored bogs.

#### Literature Cited

- Andersen, R., A.-J. Francez, and L. Rochefort (2006) The physicochemical and microbiological status of a restored bog in Québec: identification of relevant criteria to monitor success. *Soil Biol Biochem* 38: 1375-87.
- Glatzel, S., N. Basiliko, and T. Moore (2004) Carbon dioxide and methane production potentials of peats from natural, harvested and restored sites, Eastern Québec, Canada. *Wetlands* 24: 261-267.
- Rochefort, L., Quinty, F., Campeau, S., Jonhson, K., and Malterer, T. (2003) North American approach to the restoration of *Sphagnum* dominated peatlands. *Wetlands Ecology and Management* 11: 3-20.

## Does Growing Tree Stand Compensate Heterotrophic Soil Respiration on Afforested Cutaway Peatlands?

Lasse Aro<sup>\*1</sup>, Hannamaria Potila<sup>1</sup>, Kari Minkkinen<sup>2</sup>, and Jukka Laine<sup>3</sup>

<sup>1</sup>Finnish Forest Research Institute, Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano, Finland ([lasse.aro@metla.fi](mailto:lasse.aro@metla.fi)) <sup>2</sup>Vapo Ltd, PO Box 22, FI-40100 Jyväskylä, Finland <sup>3</sup>Finnish Forest Research Institute, Parkano Research Unit, Kaironiementie 54, FI-39700 Parkano, Finland

Some peat is usually left on mineral subsoil after peat harvesting. The thickness of the remaining peat layer in peat cutaway areas varies depending on the stoniness of the subsoil, subsoil topography, drainage conditions, and peat harvesting techniques. Remaining peat is usually well decomposed and compact having accordingly high amount of nitrogen. However, peat is poor in potassium and phosphorus, especially when compared to the high nitrogen store. Cutaway peatlands are susceptible to erosion due to their extent and flatness. When this is connected to extreme temperature and moisture conditions, and nutrient imbalances, cutaway peatlands are severe sites for vegetation. Therefore revegetation may be a very slow process in places without soil amelioration treatments. During slow revegetation peat decomposition continues emitting CO<sub>2</sub> to atmosphere resulting negative carbon balance of the site. Shallow peat layers may also decompose fast over coarse-textured mineral subsoils if good drainage conditions are predominant. This means quite high CO<sub>2</sub> emissions from soil to atmosphere, but also decreases nitrogen store valuable in growing forest on cutaway peatlands. CO<sub>2</sub> emissions from old peat can be compensated for by afforestation to some extent, which means the sequestration of atmospheric CO<sub>2</sub>-C into the growing tree biomass. This was studied in the peat production area of Aitoneva, in Kihniö, central Finland. Six sites were selected to represent different tree species (Scots pine and birch), developmental stages (stand ages 15-40 years), and soil characteristics (e.g., peat thickness 5–77 cm). On all of the sites peat harvesting ceased 15–20 years before afforestation. All the sites had been fertilized with potassium and phosphorus after afforestation. The soil CO<sub>2</sub> effluxes were measured using a closed-chamber system with an external infrared gas analyser during three years. The

annual soil CO<sub>2</sub> effluxes were statistically modelled using continuously measured soil temperature as the driving variable. Tree stands were measured twice in order to find out the biomass growth.

#### Literature Cited

- Aro, L. (2008) Cut-away peatlands in forestry. In: Korhonen, R., Korpela, L. and Sarkkola, S. (Eds.). Finland - Fenland. Research and sustainable utilisation of mires and peat. Finnish Peatland Society and Maahenki Ltd, Helsinki. p. 207-211.
- Aro L. and Kaunisto S. (2003) Jatkolannoituksen ja kasvatustiheyden vaikutus nuorten mäntymetsiköiden ravinnetilaan sekä puuston ja juuriston kehitykseen paksuturpeisella suonpohjalla. Summary: Effect of refertilisation and growing density on the nutrition, growth and root development of young Scots pine stands in a peat cutaway area with deep peat layers. *Suo* 54: 49–68.
- Mäkiranta, P., Hytönen, J., Aro, L., Maljanen, M., Pihlatie, M., Potila, H., Shurpali, N., Laine, J., Lohila, A., Martikainen, P.J. and Minkkinen, K. (2007) Soil greenhouse gas emissions from organic soil croplands and cutaway peatlands. *Boreal Environment Research* 12: 159-175.

## Slight Drainage May Enhance Peat Carbon Sequestration in Alder Carrs

Alexandra Barthelmes\*, John Couwenberg, and Hans Joosten

Department of Peatland Studies and Palaeoecology, Institute of Botany and Landscape Ecology, Grimmer Strasse 88, D-17487 Greifswald, Germany ([barthel@uni-greifswald.de](mailto:barthel@uni-greifswald.de))

In the waterlogged, oxygen poor environment of peatlands, cycling of matter is incomplete, resulting in the production of organic material exceeding decay and consequent peat accumulation. Peat accumulation can be caused by limitation or absence of decomposing microbes, a lack of oxidators (e.g., O<sub>2</sub>), and continuously low temperatures and can be stimulated by increased production of organic material. Also the chemical and structural composition of the produced organic matter (i.e., its decomposition resistance) is of importance. Under anaerobic conditions, for example, the decomposition of lignin is strongly inhibited and on large time scales (thousands of years) peat accumulation is largely controlled by lignin turnover.

Recent palaeo-ecological research on Holocene alder wood peat in NE Germany has shown that *Alnus glutinosa* dominated peatlands ('alder carrs') may accumulate peat (and thus carbon) in substantial quantities. Analysis of pollen, macrofossils and (because of poor fossil preservation) non-pollen palynomorphs (NPPs: i.c. wood, fungal, algal, and invertebrate remains) allowed a detailed reconstruction of the peat forming vegetation and the associated site conditions (e.g., water levels) and showed that the alder carr peat had accumulated 31–44 g C m<sup>-2</sup> y<sup>-1</sup> under very wet conditions (median annual water level: 15–0 cm above surface) and 50 to 126 g C m<sup>-2</sup> y<sup>-1</sup> under wet conditions (median annual water level: 0–10 cm below surface; Barthelmes et al., in prep.).

This observed increased peat accumulation rate with lower water levels is attributable to a substantial increase of net primary production, resulting in increased input of root biomass (largely consisting of lignin) in the deeper peat layers.

Groundwater fed peatlands generally only accumulate peat and sequester carbon with a median annual water level around the surface or above (Koska, 2001) and show net carbon emissions at lower water levels. The fact that, in contrast, very wet alder carrs increase their peat carbon sequestration capacity with falling water levels constitutes an interesting negative feed back mechanism against the drop in groundwater levels that for NE German is expected to result from climate change.

#### Literature Cited

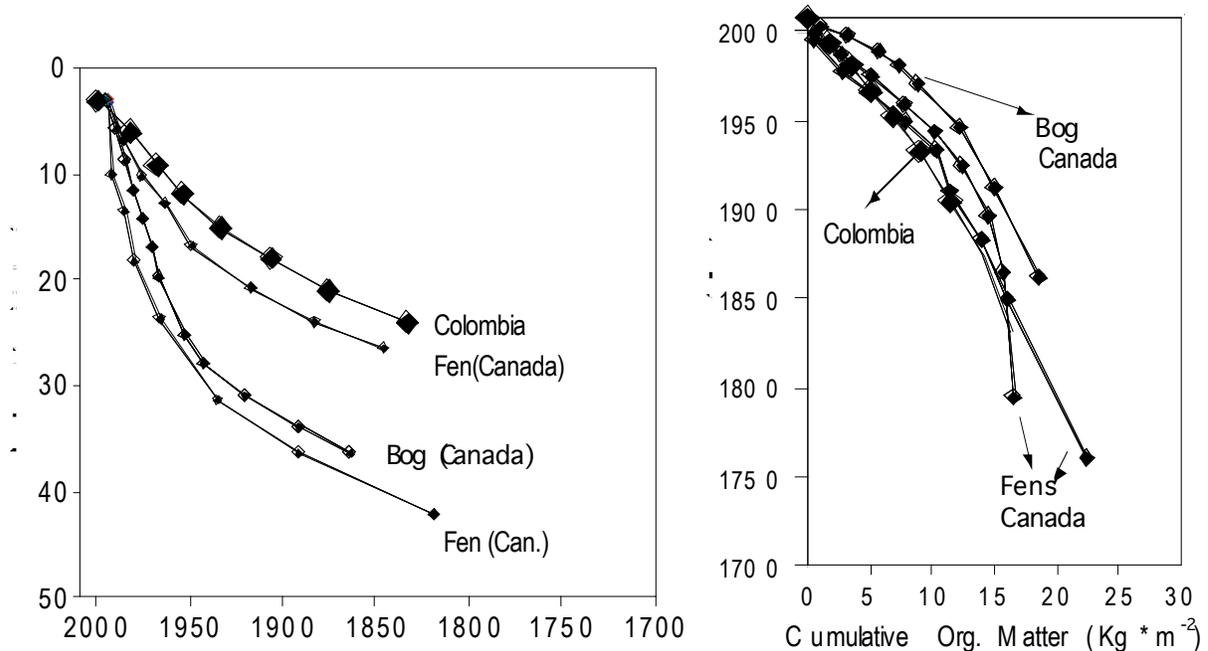
- Barthelmes, A., Couwenberg, J. and Joosten, H. (in prep.) Carbon sequestration in alder wood peat - a palaeo-ecological approach.  
 Koska (2001).  
 Koska, I., 2001. Ökohydrologische Kennzeichnung. In: Succow, M. & Joosten, H. (eds.), Landschaftsökologische Moorkunde. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, pp. 92-111.

## Peat and Carbon Accumulation in a Tropical High Elevation Cushion Bog in the Northern Andes

Juan C Benavides\*<sup>1</sup>, Dale H. Vitt<sup>1</sup> and R. Kelman Wieder<sup>2</sup>

<sup>1</sup>Department of Plant Biology, Southern Illinois University Carbondale, Carbondale, Illinois 62901, USA ([jbenavid@siu.edu](mailto:jbenavid@siu.edu)). <sup>2</sup>Department of Biology, Villanova University, Villanova, Pennsylvania 19085, USA

High elevation tropical peatlands may face even greater threats than their boreal counterparts. High elevation peatlands in the Andes are not only affected by climatic change at the same rate as boreal forests, but they are also affected by upward migrations of the agricultural fields and human settlements, starting a positive feedback between global changes, human migrations, and peatlands disturbances. High elevation tropical peatlands are thought to be crucial for water supply regulation and carbon storage, but recent measurements of peat function are lacking. In this study we report for the first time



rates of carbon accumulation during the last 200 years in a high elevation peatland in the Northern Andes. Peat was cored using a 50 x 10 cm PVC pipe and  $^{210}\text{Pb}$  dated. The peatland corresponds to a stream fen at 3400 m.a.s.l. and is dominated by cushion-forming vascular plants belonging to the Rubiaceae (*Arcytophyllum*) and Campanulaceae (*Lysipomia*). Our results show a rate of bulk peat accumulation during the last 50 years of 12 cm and a rate of organic matter accumulation of 6.6 kg/m<sup>2</sup> (see figure). Peat accumulation is much lower than the rates reported for fens and bogs in boreal forests. The lowest rate of accumulation found in a sedge dominated fen was of 16 cm and this value is well below the average for fens (Vitt et al. 2009). However organic matter accumulation during the last 50 years was similar between the high elevation Andean peatland and the boreal fens. Organic matter accumulation in boreal fens ranged from 6.5 to 13 kg/m<sup>2</sup> during the last 50 years. The similar rates of carbon accumulation may be explained by the higher bulk densities observed in the Andean peatland (0.25 g/cm<sup>3</sup>). The vascular vegetation on the surface may contain recalcitrant elements that are harder to decompose and easily compressed in the lower parts of the peat column.

#### Literature Cited

- Turetsky, M. R., R. K. Wieder, D. H. Vitt, R. J. Evans, and K. D. Scott. (2007) The disappearance of relict permafrost in boreal North America: Effects on peatland carbon storage and fluxes. *Global Change Biology* 13: 1922-1934
- Vitt, D., R. K. Wieder, K. D. Scott, and S. Faller. (2009) Decomposition and peat accumulation in rich fens of boreal Alberta, Canada. *Ecosystems* 12: 260-373.

## Successional Stage Controls Nitrogen Fixation in Boreal Mires

Andreas Berg\*<sup>1</sup>, Bo Svensson<sup>2</sup>, Mats Nilsson<sup>3</sup>

<sup>1</sup>Department of Water and Environmental Studies, Linköping University, S- 58183 Linköping, SWEDEN ([andreas.berg@liu.se](mailto:andreas.berg@liu.se)). <sup>2</sup>Department of Water and Environmental Studies, Linköping University, SE-581 83 Linköping, Sweden. ([bosseh@tema.liu](mailto:bosseh@tema.liu)). <sup>3</sup>Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, S-901 83 Umeå, Sweden.

Nutrient availability constitutes a master control on mire development. However, the development of the mire constitutes by itself an important feed-back mechanism on the nutrient input to the ecosystem. The major feature of a developing mire is accumulation of peat with significant effects on a number of ecosystem properties. With respect to nutrient availability the most important effects are disconnection to the underlying mineral soils with decreasing mire plant access to mineral nutrients. As peat accumulates also the water flow pathways from the surrounding catchment mineral soils becomes altered. (Nilsson, 2002)

A nitrogen source seldom accounted for is biological nitrogen fixation (BNF), which can contribute significantly to the overall nitrogen budget, constituting 25–82 % of the annual input in mires (Chapin & Bledsoe, 1992). The common conception is that BNF decreases as result of an increasing nitrogen pool. However, boreal mires often develop towards nitrogen deficiency.

We postulated that: in the wet areas, the successional changes in pH and mineral nutrient status will act as drivers for decreasing nitrogen fixation associated with *Sphagnum* mosses. Hence, decreasing mineral nutrient availability will further restrict the input of nitrogen,

constituting a negative feedback mechanism. To elucidate our hypothesis we investigated BNF associated with *Sphagnum* mosses in 70 wet plant communities of 31 mires of different age and development stage. The nitrogen fixation potential in all moss samples were assayed under similar light and moisture conditions in the laboratory by the acetylene reduction method. To evaluate the mechanistical controls on N-fixation the following variables were also measured P-, N-, <sup>15</sup>N and C-content, pH, peat depth, and altitude.

Nitrogen fixation decreased, as postulated, with mire age (Figure 1). The decrease was associated with a decrease in pH, moss N and P and in the relative amount of <sup>15</sup>N. Hence, successional stage of the mires affects nitrogen fixation rates as well as factors controlling the fixation.

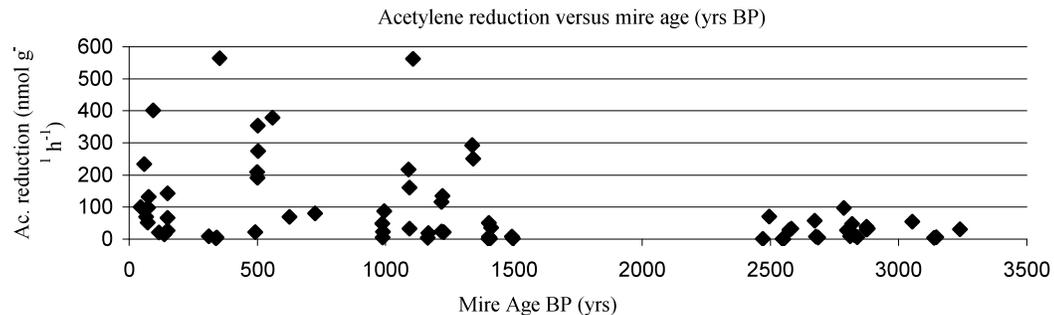


Figure 1. Scatterplot showing acetylene reduction rates for 70 sites at 31 mires at different ages.

Multiple linear regression showed pH to be the strongest predictor of acetylene reduction ( $R^2=0.31$ ). At pH below 4.5 only very low reduction rates were measured, while increasing with pH above 4.5. Moreover, the C:P quota ( $R^2=0.14$ ) was negatively correlated with acetylene reduction rates indicating the effect of P on nitrogen fixation.

We conclude that BNF is susceptible to changes in the growth conditions in the mire as forced by mire development: mainly pH and mineral nutrients.

#### Literature Cited

- Chapin DM and Bledsoe CS (1992). Nitrogen fixation in arctic plant communities. In: Chapin FS, Jefferies RL, Reynolds JF, Shaver GR, and Svoboda J (eds.) *Arctic Ecosystems in a Changing Climate*. San Diego: Academic Press, 301-319.
- Nilsson, M. B. (2002) Mire Ecosystems. *Encyclopedia of Life Sciences*: 1-8.

# **Carbon Trace Gas Dynamics of Minerotrophic Fen Peatlands in NE Germany**

**Michael Giebels, Jürgen Augustin, Madlen Beyer\*, Bärbel Ehrig, Eva Leitholdt, and Michael Sommer**

Leibniz-Centre of Agricultural Landscape Research (ZALF) e.V., Eberswalderstrasse 84, D-15374 Müncheberg, Germany ([michael.giebels@zalf.de](mailto:michael.giebels@zalf.de))

In Germany more than 99 % of fens have lost their carbon and nutrient sink function due to heavy drainage and agricultural land use especially during the last decades (Succow & Joosten, 2001; Augustin et al., 1996). But only a small part of drained and agricultural used fens in NE Germany can be restored. Knowledge of the influence of land use to trace gas exchange is important for mitigation of the climate impact of disturbed peatlands. Therefore we study carbon exchanges (i.e., fluxes) of varying fen peatland use areas between soil and atmosphere at different sites in NE-Germany. Our research covers peatlands of supposed strongly climate forcing land use (cornfield and intensive pasture) and of probably less forcing, alternative types (meadow and extensive pasture). Additionally, we do research as well at rewetted (formerly drained) areas and near-natural sites like a low-degraded fen and a wetted alder woodland. It is our aim to display the seasonal dynamics of trace gas fluxes over several years for to discover possible longterm changes. We measured trace gas fluxes with manual and automatic chambers in periodic routines since spring 2007. The used chamber technique bases on DROESLER (2005).

Due to exceptional heavy rain fall and water mismanagement in the first recorded winters most land use sites in an area of deeply drained fens in NE-Germany were flooded during summer 2007. Thus, emissions of CO<sub>2</sub> of the flooded sites were lower than expected. But due to the abnormal high methane emissions their climate balance was even worse. Other first results show impressive differences in the total annual CO<sub>2</sub> climate balance and the underlying dynamics depending on the land use management. Reflooded fen sites show a significant (i.e. several magnitudes) jump of CH<sub>4</sub> emissions in their first year of rewetting and decrease only little from year to year.

## **Carbon Dioxide and Methane Evasion from Peatland Aquatic Systems – an Important Biospheric Feedback?**

**Mike Billett\* and Frank Harvey**

Centre for Ecology and Hydrology, Bush Estate, Penicuik, Midlothian, EH10 6RE, UK, ([mbill@ceh.ac.uk](mailto:mbill@ceh.ac.uk))

Streams in headwater regions like peatlands present a unique set of challenges compared to open oceans, large rivers, estuaries, or lakes for quantifying gas exchange between the water surface and the atmosphere. For this reason there are estimates, but few measurements, of evasion rates from headwater streams. At a global scale this lack of data on CO<sub>2</sub> (and CH<sub>4</sub>) exchange in small streams has been recognized as a major “unknown” and is not included in current global terrestrial carbon budgets for inland waters (Cole et al., 2007). However, the high degree of supersaturation of CO<sub>2</sub> and CH<sub>4</sub> measured in waters draining peatland systems (e.g., Dinsmore & Billett, 2008), suggests that the evasion term in the peatland carbon budget may be important.

Here we present a series of instantaneous measurements made between 2004–2006 of CO<sub>2</sub> and CH<sub>4</sub> evasion rates from surface waters in six contrasting UK peatlands. Evasion rates are based on measuring gas exchange coefficients by the purposeful injection of conservative gas and soluble tracers (Billett & Harvey, in review). Instantaneous gas flux measurements were upscaled to the catchment scale and compared to other important (aquatic and land-atmosphere) flux terms in the peatland carbon budget.

Surface water supersaturation and evasion (degassing) of CO<sub>2</sub> and CH<sub>4</sub> was associated with all the peatland study sites and instantaneous gas exchange measurements show that fluxes of CO<sub>2</sub> were significant both on a unit area of water basis and at a catchment scale (Fig. 1). We conclude that in comparison with other peatland C flux terms, CO<sub>2</sub> evasion to the atmosphere makes an important contribution to the overall peatland carbon budget; the contribution is catchment specific and is strongly related to the hydrological drivers within the peatland system.

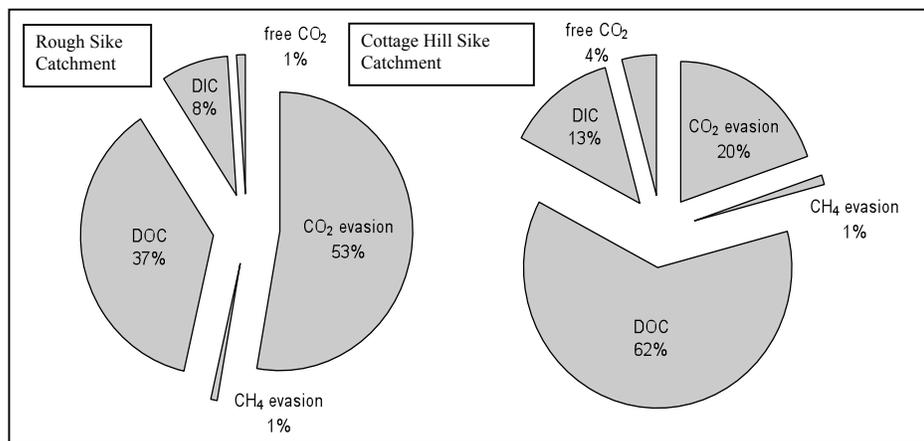


Fig 1. Importance of CO<sub>2</sub> evasion in aquatic C loss from 2 UK peatland catchments

#### Literature Cited

- Billett MF and Harvey FH. (in review) Direct measurements of CO<sub>2</sub> and CH<sub>4</sub> evasion from two UK peatland headwater streams; methods, gas exchange coefficients and fluxes. *Limnology and Oceanography*
- Cole J J and others. (2007) Plumbing the global carbon cycle: Integrating inland waters into the terrestrial carbon budget. *Ecosystems*, 10: 172-185.
- Dinsmore KJ and Billett MF. (2008) Continuous measurement and modeling of CO<sub>2</sub> losses from a peatland stream during stormflow events. *Water Resources Research* 44: W12417, doi:10.1029/2008WR007284.

# **The Extent and Classification of Peatlands in 50 Watersheds of Acid-Sensitive Lakes in Northern Alberta, Canada**

Rose Bloise and Dale Vitt

Southern Illinois University Carbondale, Carbondale, Illinois, USA ([roseb@siu.edu](mailto:roseb@siu.edu))

Up to one-third of the world's carbon is stored in peatlands (Gorham, 1991). While the extent of peatlands across the landscape of northwestern Canada is known (Vitt et al., 2000; Zoltai et al., 1988), the extent and type distribution on an individual watershed level has not previously been explored. Given the importance of peatlands on the landscape and the impending effects of climate change, knowledge of peatland, and hence carbon storage, distribution can be useful in predicating climate change effects on individual watersheds.

Using ArcGIS software and digital air photographs (scale: 1:1500), we hand-delineated the watersheds of 50 acid-sensitive lakes in northeastern Alberta. Polygons of landscape features were classified using AWI standards (Halsey et al., 2003). Data were then analyzed for dissimilarity through NMDS (non-metric multidimensional scaling) with Primer software.

The data indicate the occurrence of two types of watersheds in northeastern Alberta: upland forest-dominated and peatland-dominated. NMDS results show distinct groupings of peatland watershed types: permafrost bogs to the north, open fen-dominated to the south. Distribution of peatland type was geographically determined. Understanding the distribution and extent of permafrost peatlands is crucial to predicting carbon release in boreal peatlands; as the climate warms and permafrost melts, they will most likely degrade more quickly than other peatlands.

## Literature Cited

- Gorham, E. (1991) Northern Peatlands: Role in the carbon cycle and probable responses to climatic warming. *Ecological Applications* 1: 182-195.
- Halsey LA, Vitt DH, Beilman DW, Crow S, Mihelcic S, and Wells R (2003) *Alberta Wetland Inventory Standards Version 2.0*. Publication no. T/031. Alberta Sustainable Resource Development. Edmonton, AB, Canada.
- Vitt, D., Halsey, L., Bauer, I., and Campbell, C. (2000) Spatial and temporal trends in carbon storage of peatlands of continental western Canada through the Holocene. *Canadian Journal of Earth Sciences* 37: 683-693.
- Zoltai, S.C., Taylor, S., Jeglum, J.K., Mills, G.F., and Johnson, J.D. (1988) Wetlands of Boreal Canada. In *Wetlands of Canada* (ed C.C.o.E.L.C. National Wetlands Working Group), pp. 99-154. Polyscience Publication Inc., Canada.

# Managing Peatland Carbon in an Ecosystem Services Context

Aletta Bonn<sup>1</sup>, Chris Evans<sup>\*2</sup>, Mike Acreman<sup>3</sup>, Nesha Beharry-Borg<sup>4</sup>, Pippa Chapman<sup>4</sup>, Joseph Holden<sup>4</sup>, Mark Parnell<sup>1</sup>, Ed Rowe<sup>2</sup>, Mette Termansen<sup>4</sup>, Aki Tsuchiya<sup>5</sup> and Fred Worrall<sup>6</sup>

<sup>1</sup>Moors for the Future Partnership, Peak District National Park, The Moorland Centre, Edale, Hope Valley S33 7ZA, UK ([aletta.bonn@peakdistrict.gov.uk](mailto:aletta.bonn@peakdistrict.gov.uk)). <sup>2</sup>Centre for Ecology & Hydrology Bangor, Environment Centre Wales, Bangor, LL57 2UP, UK. <sup>3</sup>Centre for Ecology & Hydrology Wallingford, Benson Lane, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB, UK. <sup>4</sup>University of Leeds, School of Geography and Sustainability Research Institute, Leeds, LS2 9JT, UK. <sup>5</sup>University of Sheffield, Regent Court, 30 Regent Street, Sheffield, S1 4DA, UK. <sup>6</sup>Durham University, Science Labs South Road, Durham DH1 3LE, UK

There is now wide recognition of the importance of services delivered by the peatland environment that contributes to the well-being of humans. In the UK, peatlands form the biggest terrestrial carbon store, which is both a significant threat and opportunity (Evans et al., 2005). Poor peatland management of this vital store can lead to peatlands becoming net sources of carbon to the atmosphere. In turn, appropriate management can facilitate enhancement of the carbon storage, diminish the magnitude of sources or even convert present sources to sustainable net sinks (Worrall et al., 2007).

Peatlands also provide a range of other vital ecosystem services, such as 70% of the UK drinking water. Therefore, when taking action for carbon conservation in peatlands, management should strive to achieve multiple benefits and not implement action to promote one service to the detriment of other vital services (Bonn et al., 2009). Despite this, there remains little ecological understanding of ecosystem services, particularly in terms of how and where they are supplied and consumed at a regional or national scale.

Here, we identify the distribution and assess cost-benefit flows of ecosystem services in upland and lowland peatlands. The production, use and flow of benefits from nature vary spatially, and so it matters to human well-being where peatland conservation actions are implemented. Therefore, we use a spatially explicit GIS mapping approach to map and quantify distribution of key ecosystem services for four peatland case study sites in the UK, the Peak District, Migneint (N-Wales), Humber head Levels and Somerset Levels. We focus on carbon stores and compare this to water quality, potential flood risks mitigation, recreation opportunities, and biodiversity. Maps are derived from empirical data and modeling approaches using the Durham carbon model, ECOSSE and GBMOVE. In addition we scope the costs and benefits of ecosystem services from peatlands and determine suitable valuation data required to undertake peatland ecosystem service valuation based change scenarios for peatland maintenance and restoration.

## Literature Cited

- Bonn, A., M. Rebane & C. Reid (2008) Ecosystem services: a new rationale for conservation of upland environments. In Bonn, A., T. Allott, K. Hubacek & J. Stewart (eds.) Drivers of environmental change in uplands. Routledge, 448-474.
- Evans, C.D., Monteith, D.T., and Cooper, D.M. (2005). Long-term increases in surface water dissolved organic carbon: Observations, possible causes and environmental impacts. *Environmental Pollution*, 137, 55-71.
- Worrall, F., Burt, T.P., Adamson, J.K., Reed, M., Warburton, J., Armstrong, A. & Evans, M.G. (2007) Predicting the future carbon budget of an upland peat catchment. *Climatic Change*, 85, 139-158.

# Annual Carbon Dioxide and Methane Fluxes in a Canadian Boreal Peatland and their Associated Radiative Forcings and Climate Impact

Marie-Claude Bonneville\*<sup>1</sup>, Ian B. Strachan<sup>1,2</sup>, Luc Pelletier<sup>3</sup>, and Nigel T. Roulet<sup>4</sup>

<sup>1</sup>Atmospheric and Environmental Research Laboratory, McGill University, 2111 Lakeshore Road, Ste-Anne-de-Bellevue, QC, Canada H9X 3V9 ([marie-claude.bonneville@mcgill.ca](mailto:marie-claude.bonneville@mcgill.ca)); <sup>2</sup>Department of Natural Resource Sciences, McGill University, 2111 Lakeshore Road, Ste-Anne-de-Bellevue, QC, Canada H9X 3V9; <sup>3</sup> Department of Geography and Geochemistry and Geodynamics Research Center (GEOTOP), Université du Québec à Montréal (UQAM), C.P. 8888, Succ. Centre-Ville, Montréal, QC, Canada H3C 3P8; <sup>4</sup>Department of Geography, McGill University, 805 Sherbrooke Street West, Montreal, QC, Canada H3A 2K6

Peatlands exchange significant amounts of carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>), two major greenhouse gases (GHG), and thus have significant impacts on the Earth's climate. In this study, fluxes of CO<sub>2</sub> and CH<sub>4</sub> were measured in an ombrotrophic bog in North-Western Quebec, Canada. Eddy covariance measurements of net ecosystem CO<sub>2</sub> exchange (NEE) revealed that the peatland was an annual sink of about 47.7 g C m<sup>-2</sup>, which is within the range of the 6-year record of CO<sub>2</sub> fluxes measured by Roulet et al. (2007) at the Mer Bleue ombrotrophic bog. The growing season NEE was strongly correlated with incoming photosynthetically active radiation and peak CO<sub>2</sub> uptake occurred in August. Fluxes of CH<sub>4</sub> were measured on five microforms (high hummocks, low hummocks, lawns, wet depressions, and pools) using closed chambers and the resulting average annual CH<sub>4</sub> emission was estimated to be 3.2 g C m<sup>-2</sup>. Consequently, the net (CO<sub>2</sub> + CH<sub>4</sub>) annual carbon balance of this peatland corresponded to a sink of 44.5 g C m<sup>-2</sup>. A simple model based on Frohking et al. (2006) was used to quantify the individual (CO<sub>2</sub> and CH<sub>4</sub>) and total (CO<sub>2</sub> + CH<sub>4</sub>) radiative forcing associated with a persistent CH<sub>4</sub> source and CO<sub>2</sub> sink. We can therefore estimate the net climatic impact of the peatland on the Earth's radiative budget. Future potential climate impacts of the peatland were evaluated using different emission scenarios that could result in response to climatic or environmental changes. Overall, short-term impacts are driven by CH<sub>4</sub> emission rate, while the CO<sub>2</sub> flux determines the impacts on longer time horizons. Uncertainties in predicting future wetland GHG balance arise from uncertain feedbacks and responses (Roulet 2000). Future alterations of the peatland GHG emission and uptake patterns resulting from land use or climatic changes could lead to a shift in the C balance, showing the importance of peatland ecosystems in national and global C budgets and GHG-related political decisions.

## Literature Cited

- Roulet N.T. (2000) Peatlands, carbon storage, greenhouse gases, and the Kyoto Protocol: Prospects and significance for Canada. *Wetlands* 20: 605-615.
- Roulet, N.T., Lafleur, P.M., Richard, P.J.H., Moore, T.R., Humphreys, E.R., and Bubier, J. (2007) Contemporary carbon balance and late Holocene carbon accumulation in a northern peatland. *Global Change Biology* 13: 397-411.
- Frohking S, Roulet N.T. and Fuglestedt J. (2006) How northern peatlands influence the Earth's radiative budget: Sustained methane emission versus sustained carbon sequestration. *Journal of Geophysical Research* 111, G01008, doi:10.1029/2005JG000091.

# Effects of Nutrient Addition (N and NPK) on Leaf Morphology and Photosynthetic Performance of Three Bog Dwarf Shrubs

Rose M. Smith<sup>1</sup>, Sari Juutinen<sup>1</sup>, Jill L. Bubier\*<sup>1</sup> and Tim R. Moore<sup>2</sup>

<sup>1</sup>Environmental Studies Program, Mount Holyoke College, South Hadley, USA

([jbubier@mtholyoke.edu](mailto:jbubier@mtholyoke.edu)). <sup>2</sup>Department of Geography, McGill University, Montreal, Canada

Atmospheric nitrogen deposition can have serious implications for species composition, primary production, and carbon sequestration in northern peatlands. Our previous results after five years of fertilization at the Mer Bleue Bog indicated that high N (+PK) supply can reduce net ecosystem carbon uptake as a result of decreased ecosystem gross photosynthesis (Bubier et al. 2007). The present study examines possible mechanisms for this photosynthetic reduction by focusing on photosynthetic performance and morphology of the leaves of the dominant vascular species at the bog. The effects of enhanced N on photosynthesis can be variable, because the surplus N can be allocated to tissue growth or to make more efficient photosynthetic machinery. In some cases, however, high N levels have found to reduce photosynthetic capacity (e.g., Chapin & Shaver, 1996; Bauer et al., 2004). Three ericaceous dwarf shrub species selected for the study were *Vaccinium myrtilloides*, *Chamaedaphne calyculata* and *Ledum groenlandicum*. Treatments included low (1.6 g N a<sup>-1</sup>) and high (6.4g N a<sup>-1</sup>) N with and without phosphorus and potassium (PK). We measured photosynthesis for individual leaves and calculated maximum rates of photosynthesis (A<sub>max</sub>) and carboxylation (V<sub>cmax</sub>). Leaf N concentrations were determined and the morphometric measurements included length, width, thickness, area, mass and specific leaf area (SLA, cm<sup>2</sup> g<sup>-1</sup>).

Maximum light saturated photosynthesis rates (A<sub>max</sub>, μmol C m<sup>-2</sup>s<sup>-1</sup>) were similar among the species and were not affected by the treatments. *Chamaedaphne calyculata* had a significantly higher maximum carboxylation rate (V<sub>cmax</sub>, μmol C m<sup>-2</sup>s<sup>-1</sup>) than the other species in the untreated plots. Differences in V<sub>cmax</sub> among species tended to become smaller with high N addition. *Ledum groenlandicum* had significantly higher V<sub>cmax</sub> and thinner leaves in low N and low N+PK treatments than in control. In contrast, *V. myrtilloides* had significantly lower V<sub>cmax</sub> in low N plots, and larger leaf area in low N+PK plots than in control plots. Treatments did not affect V<sub>cmax</sub> or leaf morphology of *C. calyculata*. We found that species responded differently to the changed resources, and that high N additions do not reduce the photosynthetic capacity of these species, while moderate N addition might increase it. Reduced ecosystem photosynthesis under high N fertilization might be caused by changes in the light conditions for photosynthesis within the canopies.

## Literature Cited

- Bauer, G.A., Bazzaz, F.A., Minocha, R., Long, S., Magill, A., Aber, J., and Berntson, G.M. (2004) Effects of chronic N addition on tissue chemistry, photosynthetic capacity, and carbon sequestration potential of a red pine (*Pinus resinosa* Ait.) stand in the NE United States. *Forest Ecology and Management* 196: 173–186.
- Bubier, J., Moore, T.R., Bledzki, L.A. (2007) Effects of nutrient addition on vegetation and carbon cycling in an ombrotrophic bog. *Global Change Biology* 13: 1–19.
- Chapin, F.S. and Shaver, G.R. (1996) Physiological and growth responses of arctic plants to a field experiment simulating climatic change. *Ecology* 77: 822–840.

# **Peatland Degradation After Drainage in Sumava National Park, Czech Republic**

**Ivana Bufkova\* and Frantisek Stibal**

Administration of the Sumava National Park and Protected Landscape Area, Susicka 399, 341 92,  
Kasperske Hory, Czech Republic (ivana.bufkova@npsumava.cz)

Large proportion of peatlands in the Sumava Mts. (Czech Republic) have been influenced by surface drainage in the past. In 2005, both drained and intact mires were selected in the area to study degradation changes induced by disturbed hydrology and to evaluate the success of restoration. Restoration of two monitored sites was performed in summer and autumn 2008. Main restoration technique used was blocking of drainage ditches by set of board dams.

Five small catchments with different level of disturbance (control, drained and heavy drained) and including a large proportion of mires have been studied. The mire habitats under the program of monitoring are ombrotrophic peatbogs and waterlogged spruce forests. Permanent plots (71) with associated water wells were established to characterise microtopographical, vegetation and drainage patterns of the different sites. Position of water table was measured by piezometers in plastic boreholes. Water samples from boreholes, ditches and streams were taken monthly for a detailed hydrochemical analysis, including content of main cations and anions ( $\text{SO}_4$ ,  $\text{NO}_3$ ,  $\text{NH}_4$ ,  $\text{PO}_4$ , Ca, Mg, Al, Fe), pH, conductivity, and DOC. Runoff from drained catchments as well as amount of precipitation were measured continually. Vegetation was sampled in 1x1m permanent plots around each borehole. Percentage cover values for all vascular plants and bryophytes present on the permanent plots were estimated visually.

Three year of pre-restoration monitoring shows that water table was maintained in a lower position than a natural system and exhibited higher fluctuations in direct relation to the amount of precipitation received on drained sites. Water table was maintained in lower position especially on dryer dwarf shrub sites (somewhere with expanding trees) prevailing on drained bogs. Conductivity of groundwater had higher values in general on drained bogs. DOC was higher in groundwater of heavy drained sites and in ditches but much lower in runoff water from drained catchments. Concentrations of  $\text{SO}_4$  and  $\text{NH}_4$  were higher on drained bogs with the highest  $\text{SO}_4$  values in runoff surface water from drained catchment. Al concentrations had higher values in groundwater of drained mires with highest concentrations in groundwater and ditches of drained waterlogged spruce forest.

During first post-restoration phase in the autumn 2008, water table in drained bog sites rised up to a position comparable with intact bogs and exhibited low fluctuation. The effect of restoration on position of water table was less marked or none in spruce forest sites. Concentration of  $\text{SO}_4$  exhibited a decreasing trend in runoff surface water after restoration.

# **An Assessment of the Relationship between Terrestrial Carbon Cycling and Fluvial DOC Export in a Peat-Influenced Large Catchment**

Annette Burden\*<sup>1</sup>, Chris Evans<sup>1</sup>, David Cooper<sup>1</sup>, Tim Jones<sup>1,2</sup>, David Norris<sup>1</sup>, Simon Grant<sup>1</sup>, Dave Williams<sup>1</sup>, and Mark Cooper<sup>1,2</sup>

<sup>1</sup>Centre for Ecology and Hydrology, Environment Centre Wales, Deiniol Road, Bangor, LL57 2UW, UK ([anrd@ceh.ac.uk](mailto:anrd@ceh.ac.uk)) <sup>2</sup>School of Biological Sciences, Bangor University, Deiniol Road, Bangor, LL57 2UW, UK

Peatlands provide an important global resource as a major store of terrestrial carbon. In recent years, dissolved organic carbon (DOC) concentrations have increased in upland streams draining peatland systems in many regions, with uncertain consequences in terms of the long-term stability of soil carbon (Evans et al., 2007). While many factors contribute to rates of DOC export, it has been suggested that hydrological pathways and flow regimes are a major control in DOC flux (Worrall & Burt, 2007), and may be the major driver of future variability (Erlandsson et al., 2008). Here we use data from an integrated monitoring programme in the Conwy catchment (North Wales, UK) which couples continuous stream chemistry and flow measurements with monthly soil water and stream sampling, to investigate the relationship between terrestrial carbon cycling and stream DOC concentrations. At the small catchment scale, we explore the relationship between soil and stream water DOC concentrations, and the relationship with short-term climatic and hydrologic variation (temperature, stream discharge and water table depth). At the larger catchment scale, we use a landscape-based mixing model to estimate the contribution of peatland DOC export to the overall fluvial carbon budget, and the delivery of carbon to coastal waters. We also present data on qualitative differences in DOM constituents exported from peatland and non-peatland sources, and estimate the potential reactivity of DOM from these different sources within the river network, from headwaters to the estuary.

## Literature Cited

- Erlandsson, M., Buffam, I., Fölster, J., Laudon, H., Temnerud, J., Weyhenmeyer, G.A., and Bishop, K. (2008) Thirty-five years of synchrony in the organic matter concentrations of Swedish rivers explained by variation in flow and sulphate. *Global Change Biology* 14: 1191-1198.
- Evans, C.D., Freeman, C., Cork, L.G., Thomas, D.N., Reynolds, B., Billett, M.F., Garnett, M.H., and Norris, D. (2007) Evidence against recent climate-induced destabilisation of soil carbon from <sup>14</sup>C analysis of riverine dissolved organic matter. *Geophysical Research Letters* 34: L07407, doi:10.1029/2007GL029431
- Worrall, F., and Burt, T.P. (2007) Flux of dissolved organic carbon from U.K. rivers. *Global Biogeochemical Cycles*, 21, GB1013, doi:10.1029/2006GB002709.