Methane Fluxes in a Semi-Natural N Perturbed Ombrotrophic Peat Bog

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Whim Moss is a semi-natural peat bog in the Scottish Borders where a novel N manipulation program has been carried out since 2002 (Sheppard *et al.* 2004). Enhanced reactive nitrogen deposition may compromise the sustainability and functioning of bogs, with respect to carbon sequestration and greenhouse gas production (Segers 1998). Investigations are being carried out in to the effects of different forms and concentrations of N at all levels of the ecosystem - three N forms; NH_3, NH_4^+, and NO_3, have been applied to an ombrotrophic bog growing *Calluna, Sphagnum capillifolium,* and *Eriophorum vaginatum* in order to test this. Significant changes in species cover and soil chemistry, especially in response to elevated ammonia concentrations, have been recorded (Sheppard *et al.* 2008).

This paper will report on the production and consumption of CH_4 at the different forms and concentrations of N and investigations of important drivers and the underpinning microbial communities.

Methane fluxes are measured in the field on a monthly basis together with N_2O using closed static chambers with additional measurements being taken, depending on climatic conditions including freeze-thaw events and during droughts. To investigate further the drivers of methane consumption and production the pH of both soil and pore water from rhizon samplers was measured and N analysis of the water determined each time fluxes were measured. Climate data is continuously collected automatically including soil and air temperature and rainfall.

There is a need for a greater understanding of microbial processes within soils; especially regarding processes resulting in net emission of the greenhouse gases N_2O and CH_4 and DNA analysis to identify microbial communities and laboratory experiments will be undertaken to quantify CH_4 oxidation rates under a range of N concentrations, water table depths, temperature, and pH, and related to the underpinning microbial diversity.

Literature Cited

Segers R. (1998) Methane production and consumption: A review of processes underlying wetland methane fluxes. *Biogeochemistry* 41: 23-51.

Sheppard L. J, Crossley A, Leith I. D. *et al* (2004) An automated wet deposition system to compare the effects of reduced and oxidised N on ombrotrophic bog species: practical considerations. *Water, Air, and Soil Pollution: Focus* 4: 197-205.

Sheppard L. J., Leith I. D., Crossley A. *et al*. (in press) Stress responses of *Calluna vulgaris* to reduced and oxidised N applied under 'real world conditions'. *Environmental Pollution*.

Bioclimatic Envelope Modeling of the Present Global Distribution of Boreal Peatlands

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Natural wetlands cover ~8-10 million km^2 of the earth's surface and approximately 20% of the world's soil carbon is stored in boreal and subarctic peatlands where it has been accumulating gradually under wet and cool climatic conditions since the end of the last ice age. The carbon balance in these ecosystems is likely to be affected by global warming, although the overall effect i.e., whether changes will have a net positive or negative impact on irradiative forcing, is not yet clear (Turetsky et al., 2007). The large area of peatlands currently under permafrost is particularly susceptible to climate change. Warming has been predicted to be the most pronounced at high latitudes. Thawing of the permafrost in arctic and boreal peatlands favors carbon accumulation due to an increase of net ecosystem production (Turetsky et al., 2007). However, peatland ecosystems at lower latitudes may not be well adapted to survive the more frequent extreme heat waves predicted as part of global warming and low boreal peatlands may migrate northwards as a result of elevated temperatures and drought. Bioclimatic envelope modeling is an appropriate technique to study the current distribution of peatlands and to project the potential changes under future climate scenarios. Regional distribution of peatlands have successfully been mapped in Canada (Gignac et al., 2000) and Fennoscandia (Parviainen & Luoto, 2007) using various bioclimatic models. We plan to study the zonation of peatlands at a global scale using STASH, a model that attempts to find the most meaningful bioclimatic variables that characterize the physiological limits of a given ecosystem or species (Sykes et al., 1996). The predictor bioclimatic variables will be specifically chosen to best differentiate between each observed mire complex type so that changes in peatland zonation can be predicted under future climate scenarios. Within this modeling framework we shall identify the major sources of uncertainty in our model predictions and discuss strategies for a risk based approach to peatland zonation changes.

Literature Cited

Gignac, L.D., L.A. Halsey, and D.H. Vitt. (2000) A bioclimatic model for the distribution of *Sphagnum*-dominated peatlands in North America under present climatic conditions. *J. Biogeogr*. 27:1139-1151.

Parviainen, M., and M. Luoto. (2007) Climate envelopes of mire complex types in Fennoscandia. *Geogr. Ann. Ser. A-Phys. Geogr*. 89A:137-151.

Sykes, M.T., I.C. Prentice, and W. Cramer. (1996) A bioclimatic model for the potential distributions of north European tree species under present and future climates. J. Biogeogr. 23(2):203-233.

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. *Glob. Change Biol.* 13: 1922-1934.

Diurnal Temperature Effects on the Production of Trace Gases in Peatland Soil

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Peatland soils are important reservoirs in the global carbon cycle and there is much interest in characterising the response of their carbon stores to temperature perturbations. Peatlands are notable also because of their dual function as carbon capacitors and amplifiers in the Earth System, sequestering CO_2 into soil organic matter, but also producing CH_4, a greenhouse gas more potent than CO_2. Several syntrophic groups of microorganisms are responsible for anaerobic mineralisation of organic matter in peatlands and the production of CH_4 is inextricably linked to cycling of H_2 and CH_3COOH, which are generated from fermentation reactions higher in the chain of decay. It remains unclear how differences in the temperature optima of the various syntrophic microorganisms interact in a cyclical temperature regime to effect total yield of CH_4. Our study adapted a novel heating and cooling instrument, the Metz Syn[10], typically used for process chemistry, as a new form of soil incubator. The instrument is capable of generating cyclical and ramped temperature regimes and this feature was exploited to simulate real-time diurnal soil temperature variations while measuring concentrations of CH_4, CO_2 and H_2 at a temporal resolution of every six minutes. The peat samples were obtained from the acrotelm and catotelm of a raised bog (Cors Caron) and an intermediate fen (Crymlyn Bog) both located in Wales, UK. The peat was incubated anaerobically in three different temperature regimes: constant stepped, cyclical and ramped. The gas concentration data were used to calculate production rates, F-ratio (ratio of CH_4 production to CH_4 + CO_2 production rates), Q_{10} factors, activation energy and Gibbs free energy values for specific microbial processes, namely hydrogenotrophic methanogenesis and CO_2 and H_2 production. Determinations of these parameters from the cyclic temperature regimes were compared to values from conventional stepped temperature incubations that are presently used in most models of anaerobic carbon mineralization in peatland soils. Lower rates of methanogenesis occurred in cyclical versus constant temperature incubations in acrotelm peat from the fen but none of the other samples. Temperature sensitivity of anaerobic CO_2 production in peat soils was linked positively to nutrient status. Rates of H_2 production were similar for all temperature regimes and responded rapidly to variations in temperature, driving similar but delayed changes in rates of methanogenesis. Gradually ramped temperature (0.6°C h^{-1} up to 70 °C) incubations allowed the determination of the optimal temperature of methanogenic communities present in each sample as well as the maximum temperature at which microorganisms responsible for terminal anaerobic carbon mineralization could function. Nutrient status of a peatland appears to influence the ability of microbial communities responsible for carbon turnover to respond to changes in temperature. Q_{10} values for fens determined from conventional temperature-stepped incubations may overestimate the response of methanogenesis to variations in temperature. Methane production in peat from ombrotrophic peatlands responds similarly to both stepped and cyclical temperature regimes.

The Holocene Carbon Dynamics of Boreal and Sub-Arctic Peatlands Following a Nordic Gradient in Québec: A Synthesis for North-Eastern Canada

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Since the Holocene period, peatlands have stored a large amount of carbon (250–450 Pg C) which corresponds to approximately 30% of the world soil C and 25 to 50% of the actual atmospheric CO_2 burden (Frolking & Roulet, 2007; Turunen et al., 2002). In Canada, most studies on peatlands carbon dynamics have taken place in the continental western (Alberta) and central regions (Ontario). Although, peatlands represent between 9 and 12% of the Quebec province territory, knowledge on their holocene C dynamics was still limited until a recent research program was initiated by Garneau et al. in regions following a nordic gradient from mid-boreal (52° N) and to subarctic (55° N) latitudes. Results of peatlands carbon accumulation from Eastmain (mid-boreal) to Kuujjuarapik (subarctic) show a biodiversity of peatland types and related carbon dynamics primarily related to ambient hydroclimatic conditions. Climate gradient from the studied regions range from -2.08 °C to – 4.03 °C in terms on mean annual temperature and 732 to 653mm in terms of mean annual precipitations.

Peatlands characteristics vary from large ombrotrophic complex in mid-boreal latitudes with mean depths of 215 cm and mean LORCA and RERCA of 17.7 and 78.5 g m^{-2} y^{-1} respectively. In subarctic region, ombrotrophic peatlands are replaced by minerotrophic peatlands with mean depths of 170 cm and mean LORCA and RERCA of 10.8 and 52.6 g m^{-2} y^{-1} respectively. All regions have registered variations in peat accumulation through the Holocene that can be linked with climate (temperature and precipitation). The Little Ice Age cooling influenced peatlands dynamics with evidence of permafrost aggradation in most regions. The past 150–100 years is characterized by a rise in peat accumulation linked with an overall rise of humidity in northern Québec as shown by other proxy records (Bégin, 2001). Predictions (2041–2070) of the CRCM (Canadian Regional Climate Model, Consortium Ouranos) show rise in both temperatures and precipitations with most important changes during the winter season. These results confirm the importance of understanding the links between climate and peatland carbon sequestration in order to identify their contribution to the global atmospheric carbon cycle in the near future.

Literature Cited

Frolking, S. and Roulet, N.T. (2007) Holocene radiative forcing impact of northern peatland accumulation and methane emissions. *Global Change Biology* 13: 1079-1088.

Turunen, J., Tomppo ,E., Tolonen, K., and Reinikainen, A. (2002) Estimating carbon accumulation rates of undrained mires in Finland – application to boreal and subarctic regions. *Holocene* 12: 69–80.

Year-Round Measurements of Carbon Dioxide and Methane Exchange from a Boreal Peatland in Northwest Russia

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The majority of natural wetlands (peatlands) are situated in the boreal region. Many studies related to carbon exchange in wetlands have been conducted in North America and Fennoscandia, but the vast mire ecosystems in Russian boreal region have not been studied extensively. Here we present a study from a wet boreal peatland in Komi republic in Northwest Russia. Measurements of carbon dioxide (CO_2) and methane (CH_4) were performed from early spring 2008 to late winter 2009 using the eddy covariance method. Cold season CH_4 fluxes in the beginning of the measurements were ~0.5 mg m^{-2} h^{-1} when snow cover was present, rising up to ~5 mg m^{-2} h^{-1} during snowmelt. With transition to spring and following plant development, CH_4 fluxes rose rapidly and reached as much as ~12.5 mg m^{-2} h^{-1} in late June. Due to technical problems no data are available for July 2008. In August, the end of summer, CH_4 flux still reached ~10 mg m^{-2} h^{-1}. From the middle of August plant senescence was visible and CH_4 fluxes were steadily decreasing as winter was approaching. CO_2 efflux was very modest when snow cover was present, reaching up to 10 µg m^{-2} s^{-1} and up to ~50 µg m^{-2} s^{-1} during snowmelt when the ice layer on the peat surface was melted. After the snowmelt, diurnal pattern in CO_2 dynamics could be observed while mosses were the first green plants on the peatland. From the middle of May vascular plants were rapidly developing and daily uptake was higher than nocturnal respiration. During the summer, daily uptake reached as much as ~ -500 µg m^{-2} s^{-1}, while nocturnal efflux reached ~190 µg m^{-2} s^{-1}. Strong decline in CO_2 flux could be observed from the beginning of September. In the middle of October nocturnal efflux was higher than daily uptake and from the beginning of November daily uptake ceased completely. Here, we discuss the gaseous component of the carbon dynamic from a boreal peatland throughout the year while aiming to determine their environmental controls. Furthermore sink/source strength based on gaseous carbon flux of boreal peatlands in continental climate will be discussed.

Carbon Accumulation by Mires in the Southern Taiga of Western Siberia

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Peatlands play an important ecological role in the biosphere. They are sources and sinks of greenhouses gases and keepers of the biological diversity. Peatlands could provide a significant positive feedback to climate changes if warming stimulates bulk soil organic matter decomposition and CO_2 release to the atmosphere.

The assessments of local carbon balance of basic mire ecosystems were obtained from the results of long-term (2005–2008) instrumental observations of CO_2 emission, net primary productivity, at field station "Vasuganie" and adjoining areas. Analysis of LANDSAT space images revealed 24 landscape types. The total studied area (496877 ha) is occupied by upland forests (39.76%) and mires (45.1%). Basic mire ecosystems are represented by high ryam (pine-sedge-*sphagnum* phytocenosis) (13.71%), low ryam (10.26%), open bog (6.16%), ridge-hollow complex (RHC) (4.85%), and rich open (2.21%) and wooded (5.14%) fens.

Estimations of local carbon balance for different ecosystems in combination with classification of vegetation types provide calculation of regional carbon balance for peatland ecosystems at the studied area. We have found that peatlands sequestrate 1.88 10^{11} gC/yr from the atmosphere. The area average carbon accumulation rate is 84.9 gC/m^2/yr. Peatlands of Western Siberia are a significant, active biosphere carbon sink in the present climate. Future change may alter the accumulation regularities and change peatlands to carbon source.

Table 1. Carbon balance for different peatland ecosystems.

	Area, ha	Emission, gC/m^2/yr	NPP, gC/m^2/yr	Carbon balance, gC/m^2/yr	Accumulation rate, tC/yr
Tall ryam	68 155	250,2	268,1	17,9	12 200
Low ryam	50 980	165,4	282,6	116,2	59 239
RHC	24 113	331,1	371,6	40,5	9 766
Open bog	42 136	168,5	274,1	105,6	44 495
Rich open fen	10 997	224,7	506,9	282,2	31 032
Rich wooded fen	25 554	318,4	442,5	124,1	31 713
Total	221 934				188 444

Carbohydrates and PLFAs as Proxies for Plant Inputs and Microbial Degradation in a *Sphagnum*-dominated Peatland

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To infer plant inputs and identify biopolymer degradation and microbial communities structures associated to this degradation, we studied the patterns of microbial phospholipid fatty acids (PLFAs) and cellulosic and hemicellulosic sugars from the uppermost 50 cm of a peat deposited in an undisturbed ombrotrophic *Sphagnum*-dominated peatland located in the French Jura mountains.

Particular emphasis was devoted to carbohydrates analysis given (i) their important role in the constitution and metabolism of the peat-forming plants and (ii) the slight degradation they undergo in the peat. In fact, contrary to commonly perceived ideas which stipulate a highly biodegradability, we recently demonstrated that sugar compounds are well preserved in peat allowing their use both as indicators of humification and as tracers of plant sources [1].

Both carbohydrates and PLFAs were analysed at ten different sampling depths between 0 and 50 cm. Neutral sugars were recovered after two hydrolyses releasing the total and the hemicellulosic sugars, respectively. The cellulosic sugars were determined by difference.

Analysis revealed that the degree of depth-related variation in PLFA composition was high. PLFAs from both Gram-negative and Gram-positive bacteria had maximum concentrations slightly below the average water table depth and, to a lesser extent, few centimeters below the moss surface. At the average water table level, a strong decrease of inherited plant sugars (total carbohydrates, cellulosic glucose, galactose xylose and arabinose) was recorded. The PLFA that has been suggested as an indicator for protozoa, arachidonic acid [2], was poorly detected along the peat profile. It was absent below the water table but shows a maximum concentration from 5 to 7 cm below the surface. At the same depth (5 to 15 cm), a relative increase of ribose, fucose and lyxose contents were also detected. The PLFA 18:2ω6, common in many species of fungi [2], was detected only from 5 to 15 cm depth where microscopic observations also revealed high proportions of fungi hyphae. Therefore, the increase of ribose, fucose and lyxose contents at this depth may result from microbial synthesis mainly deriving from protozoa and fungi activity.

These results show (1) an evident link between carbohydrates and microbial structures showing the irregularity in the consumption of plants sugars by microorganisms along the first 50 cm of a peat deposit occurring mostly just below the moss surface and at the accrotelm peat layer, (2) the potential of sugars as biomarkers of source and degradation which are currently under-utilised as proxies for plant and microbial inputs in peatland ecosystems.

Literature Cited

Comont, L., Laggoun-Défarge, F., and Disnar, J.-R. (2006) Evolution of organic matter indicators in response to major environmental changes: the case of a formerly cut-over peatbog (Le Russey, Jura Mountains, France). *Organic Geochemistry* 37: 1736-51

LeChevalier H. and LeChevalier M. P. (1988) Chemotaxonomic use of lipids – an overview. In: *Microbial Lipids Vol. 1.* Ratledge, C. and Wilkinson, S.G. (eds.) pp. 869–903. Academic Press Ltd., London.

Mapping the Extent of Peatlands using Decision Tree Modeling, Indicator Kriging and Legacy Soil Information

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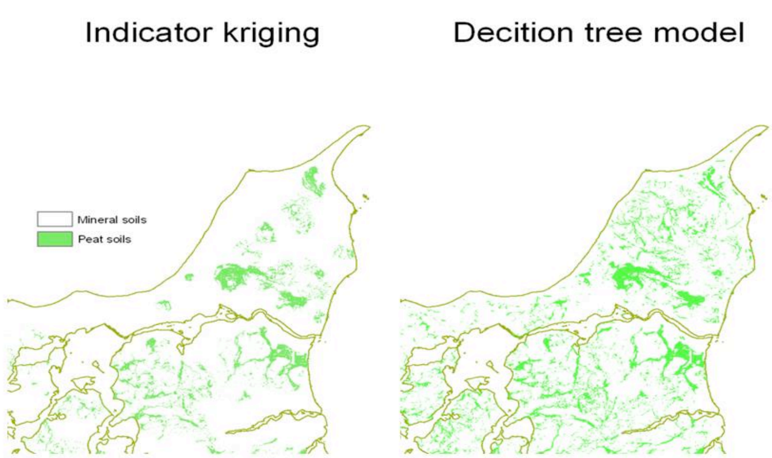
In ratifying the Kyoto CO_2 Protocol, Denmark has chosen to fulfill article 3.4, which recognises sources and sinks of biospheric carbon (including Forest Management, Cropland Management, and Grassland Management). This implies the mapping of the carbon stock of the cultivated peatlands. The present knowledge of the peatlands and their geographical distribution in Denmark is derived from a range of different surveys and investigations carried out during the last 150 years. Previous inventories of carbon stocks in Danish soils have put very little emphasis on these areas.

As part of the four year 3.5 mill $ contract with the Danish environmental authorities, University of Århus will assess the contemporary stock of organic carbon in peatlands. Peatlands are in the context of this project defined as soil with more than 10% organic matter in the topsoil. There is a range of national legacy soil data available for the delineation of the peatlands. The data are very different in age and quality. We have both legacy point, polygon and raster data available for the survey.



This paper concerns the delineation of peatlands that should be done using GIS and legacy soil information. We compare two prediction methods for mapping the extent of the peatland. The preliminary analysis of the polygon data shows that 20.5% of Denmark is - or have been - wetland soils (mineral or organic).

Indicator kriging is as described by Oliver and Webster (1991) and provides probabilities of a property exceeding a threshold at unobserved location. The exper-imental variogram was calculated using a lag size of 2000 m and 12 lags. A spherical model was fitted and sill, nugget and range were estimated to 0.21, 0.11 and 16700 m. We have estimation maps showing the probability of organic soil (> 10% organic matter). The areas covered with peat using 40% probability are 32% of the wetland area. Both the low sill to nugget ratio, indicating a week spatial correlation and the very long range gives us a map showing only the very large pattern of the distribution of the peat soils. More points has to be included if indicator kriging should be used.

The decision tree modelling is based on legacy soil information, DEM derivatives and RS indices. Using this method 30% of the wetlands are classified as peatlands. The results from the two methods are shown in Figure 1.

Literature Cited

Henderson, B.L., Bui, E.N., Moran, C.J., Simon, D.A.P. (2005) Australia-wide predictions of soil properties using decision trees. *Geoderma* 124: 383-398.

Oliver, M.A., and Webster, R., (1991) How geostatistics can help you. *Soil Use Management* 7: 206–217.

Scull, P., Franklin, J., and Chadwick, O.A., (2005) The application of classification tree analysis to soil type prediction in a desert landscape. *Ecological Modelling* 181: 1-15.