

Organic Matter Dynamics in a *Sphagnum*-dominated Peatland Colonised by *Molinia caerulea* and *Betula* sp.

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Peatlands are important CO₂ sink and CH₄ source at the same time. As such they play a major role in the regulation of the global carbon (C) cycle and the climate of the earth. However, under changes produced by human activities, their functioning may switch from sink to source of C. Colonisation of peatlands by trees and grasses is a natural process that may be accelerated by global and/or local changes (i.e., drainage, nutrient input). The new species through their root system and litter input may affect the accumulated organic matter (OM) composition as well as the soil conditions and thus, may reduce the capacity of the peatland to store C. The aim of the study is to understand the biochemical processes occurring in surface peat following *Molinia caerulea* and *Betula* sp colonisation. The study site is a French peatland (La Guette) that has been recently colonised by *Betula verrucosa*, *Betula pubescens* and *Molinia caerulea*.

Two areas within the peatland were being considered along a wetness gradient. Within each of these areas, 2 plots of 4m² surface were chosen depending on vegetation: 2 open plots (treeless) and 2 close plots (with trees and *Molinia*). Four cores (50 cm) were collected in the 4 plots. Pyrophosphate index (PPI), C/N, and Rock Eval (RE) pyrolysis parameters (e.g., R400) were measured along the peat profiles. Litters of *Sphagnum cuspidatum* and *S. rubellum*, *Molinia caerulea* and *Betula verrucosa* were collected and 100 litter bags (25 for each vegetation) of 0.5mm mesh were placed in 5 decomposition habitats of each vegetation (5 bags per habitat). At 1, 3, 6, 12, and 24 months, one bag in each habitat is retrieved. Remaining mass, CNS content, RE parameters and neutral sugars are measured at each date.

Results showed that in areas colonised by vascular plants, Dissolved Organic C (DOC) and PPI were higher than in open areas. R400 profiles (which high value reflects relatively fresh OM) demonstrated that in one colonised area, surface OM was more decomposed than just below, whereas in all other areas, R400 was higher at the surface than any other depth below. These results suggest that tree and *Molinia* colonisation stimulates OM decomposition (OM content, DOC, PPI) and the mechanisms leading to this stimulation may differ between invaded areas (R400). These different mechanisms still need to be investigated. We hypothesised that the litter of colonised plant is more readily decomposable. The increased decomposition would release higher amount of DOC and inorganic nutrients. Supplementary DOC can trigger priming effect and increased inorganic nutrients may impede *Sphagnum* production, which in term would damage the C storing capacity of the system.

OM decay kinetic study would help testing the above hypothesis. The three types of vegetation (*Sphagnum* sp, *Molinia caerulea* and *Betula verrucosa*) differ in their chemical quality as shown by RE pyrolysis and ash content. Relation between chemical characteristics of the litter (C/N, carbohydrate content, RE parameters) and decomposition constant (k) is attempted. At the end, a feedback mechanism model is proposed to explain the switch of vegetation in this site and implication of this feedback on C sink capacity of the system is discussed.

Identification of Labile Water Soluble Organic Compounds from a *Sphagnum*-dominated Peatland. Molecular and Isotopic Signatures

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In the context of global warming, one scenario is the acceleration of decomposition of organic matter (OM) with a resulting increase of the CO₂ concentration in the atmosphere. *Sphagnum*-dominated peatlands are now recognised as valuable pools of sequestered C and their response to predicting potential feedbacks on the global C cycle becomes crucial (Davidson & Janssens, 2006). Within the PEATWARM project (PEATWARM website), funded by French National Research Agency, we aim to determine the effects of moderate warming on OM dynamics in the peat substrate. The labile organic compound reactivity was studied in priority in Dissolved OM (DOM) pool. Our prior studies have in fact shown the abrupt release of simple products (sugars, fatty acids...) by the hydrolysis of complex organic compounds during the initial stages of early diagenesis (Bourdon et al., 2000). In addition to these products, those from microbial neosyntheses were found preferentially concentrated in the aqueous phase. Therefore, DOM would highly be reactive to warming and thus constitutes a suitable target.

Water which has been extracted from surface peat layers (10 – 12.5 cm depth) was subjected to both carbohydrate and size exclusion LC-irMS of C stable isotope analyses. Neutral sugars were recovered without hydrolysis (fraction 1) and after H₂SO₄ hydrolysis (fraction 2). Water from piezometers at 15 cm depth was also analysed by LC-irMS at two seasons (on June and November 2008). The Dissolved Organic Carbon (DOC) was also determined.

Total content of dissolved carbohydrates (fraction 2) was ca. 7 mg.g⁻¹ that about 50% was present as free monosaccharides (fraction 1), mainly as hemicellulosic glucose (2.55 mg.g⁻¹). The fraction 2 was composed of glucose, galactose, rhamnose, xylose, arabinose and mannose derived probably from inherited-plant oligo- and/or polysaccharides. Only fucose, present in very low proportion (0.17 mg.g⁻¹), could result from microbial synthesis.

δ¹³C/¹²C isotopic signatures of peat extracted water identified by LC-irMS with a gelfiltration column (Biobasic SEC300) revealed a major (80 to 90% of DOC) macromolecular fraction (molecular weight 14-16 kDa) with an isotopic signature of -24 to -26‰ characteristic of photosynthetic origin. A minor fraction with a very high molecular weight (ca. 106 Da) which had an isotopic enrichment in ¹³C of about 3‰ (-20 to -24‰) relative to the major fraction was also revealed in peat extracted water. The latter fraction being only present in water collected at summer was suspected to be sensitive to seasonal variations and would be the most reactive pool to warming.

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PEATWARM project aims to determine to what extent C sink function of Sphagnum-dominated peatlands can be modified in a context of climatic warming using an experimental system (ITEX) that simulates in situ a moderate increasing of temperature (<http://peatwarm.cnrs-orleans.fr>)

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Amazonian Peatlands: an Ignored C Sink and Potential Source

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Peatlands are commonly reported in tropical lowlands of Southeast Asia, particularly Indonesian tropical peatlands are known as considerable C sinks and sources (Page et al., 2002, 2004). In contrast, Amazonia has been clearly understudied in this context (Schulman et al., 1999). In this study, based on field observations from 17 wetland sites in Peruvian lowland Amazonia, we report 0–5.9 m thick peat deposits from 16 sites. Only one of the studied sites did not contain any kind of peat deposit (considering pure peat and clayey peat). Historic yearly peat and C accumulation rates, based on radiocarbon dating of peat samples from five sites (Fig. 1), varied from 0.94 ± 0.99 to 4.88 ± 1.65 mm, and from 26 ± 3 to 195 ± 70 g C m⁻², respectively. The long-term apparent peat and C accumulation rates varied from 1.69 ± 0.03 to 2.56 ± 0.12 mm yr⁻¹, and from 39 ± 10 to 85 ± 30 g C m⁻² yr⁻¹, respectively. These accumulation rates are comparable to those determined in the Indonesian tropical peatlands. Under altered conditions, Indonesian peatlands can release globally relevant amounts of C to the atmosphere (Page et al., 2002). Considering the estimated total area of Amazonian peatlands (150,000 km²; Schulman et al., 1999) is close to that of the Indonesian peatlands (200,728 km²), and that several factors threaten the Amazonian peatlands, we suggest that the total C stocks and fluxes associated with Amazonian peatlands may be of global significance.

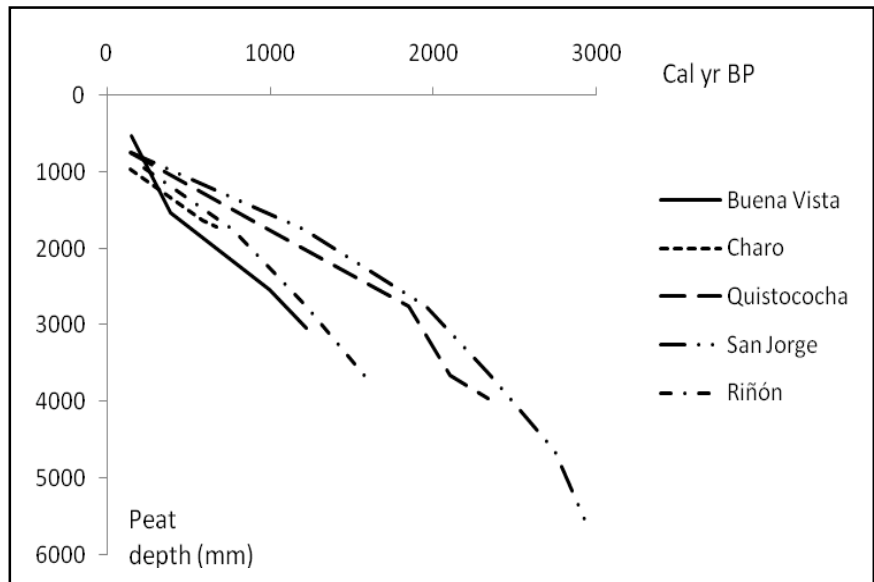


Figure 1: Age-depth curves based on the calibrated radiocarbon ages (from Lahteenoja et al., in press, *Global Change Biology*)

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Bog Scale Variation may Overshadow Continental Scale Variation in Bog Photosynthesis

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Despite their low productivity ombrotrophic bogs have been shown to be more efficient carbon sinks than nutrient richer fens (e.g., Turunen et al., 2002). Although the climax ecosystem concept and successional development towards higher stability has been strongly questioned in contemporary ecology, mire scientists commonly consider bogs as the final stage in mire succession. Typically, bogs have a predictable internal variation in vegetation that is related to variation in water level, namely hummock – hollow-gradient. This variation may act as a mechanism for ecosystem resilience: high structural diversity allows co-existence of several functionally different species that support carbon sink functioning under various conditions. Our large data set from different parts of Europe (Laine, Karofeld, Oksanen, Oksanen, Sillasoo, Tuittila, Välranta, Wilson, unpublished data) shows that the internal variation within plant communities of a single bog can be as large as the variation that exists between bogs of highly different climatic regions. Here we aim to study whether functional diversity follows the same pattern as vegetation by comparing variation in photosynthesis between and within different bogs.

We measured CO₂ exchange from four bog sites located in Ireland and Finland using the closed chamber method. We studied the photosynthetic response of different plant communities and have expressed gross photosynthesis (P_G) per leaf area. We related the main growing season (mid July to mid August) P_G to photosynthetic photon flux density (PPFD) by using a hyperbolic function: $P_G = P_{max} * ((PPFD)/(k + PPFD))$, where P_{max} is the maximal rate of photosynthesis and k is the half saturation constant. We used ANOVA to test the differences in P_{max} and k between sites. We applied Principal Component Analysis to visualize the diversity in functioning (P_{max} , k , vascular leaf area, moss cover, water level) between and within the bogs.

The average, maximum and minimum P_{max} was 0.94, 2.07, and 0.33 g CO₂ leaf area m⁻² h⁻¹, respectively. According to ANOVA ($p = 0.06$) the variation in P_{max} was higher within than between the sites. This was confirmed by the PCA analysis. The most important component

(axis 1, with eigenvalue 0.864) described the productivity, combining the potential photosynthetic efficiency of vegetation (P_{max}) and photosynthesizing vascular leaf area. Second component (axis 2, with eigenvalue 0.081) described the weak regulation of water level over moss cover, which is not linked with productivity. Our results support the hypothesis of high functional diversity within bogs, which may overshadow continental scale variation.

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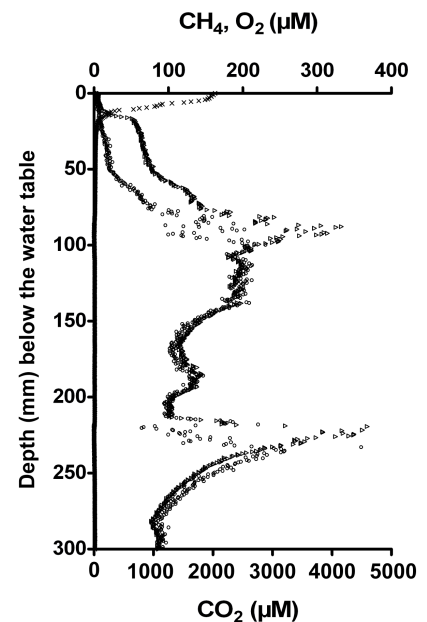
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Methane from Peat Bogs: Investigating Zones of Peak Production

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The majority (98%) of CH_4 released from the peatland surface originates from the first 500 mm below the water table. Using Quadrupole Mass Spectrometry (QMS) we describe the *in situ* distribution of the gases CH_4 , CO_2 , and Ar at 0.6 mm vertical resolution in 300 mm deep cores from an ombrotrophic bog. Within and between core variability in gas profiles is quantified in both hollows and hummocks and the location of bubbles is identified *in situ*. Direct links between the physical structure of peat and distribution of microbial communities have also been investigated to identify the determinants of gas distribution.



Evaluating the Effects of Holocene Hydroclimatic Changes on Carbon Dynamics in a Permafrost Peatland, Kuujjuarapik, Northeastern Canada

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In order to improve the comprehension of the impacts of permafrost aggradations on carbon dynamics, multi-proxy analyses are realized to reconstruct Holocene paleohydrological conditions and related methane dynamics. Peat cores were extracted from three different environments (modern palsa, collapsed palsa, and forested peatland margin) in a permafrost peatland located near Kuujjuarapik, in the southern limit of the sporadic discontinuous permafrost zone in subarctic Quebec (55°13'N, 77°41'W). Testate amoebae and plant macrofossil analyses are used to assess past hydrological conditions since the beginning of peat accumulation in the region (≈6000 BP) (Arlen-Pouliot & Bhiry, 2005). A northern Quebec water-table depth transfer function using testate amoebae assemblages will be developed to infer past water-table depth by analysing modern assemblages from several sites following a nordic transect from boreal to subarctic Quebec (Charman et al., 2007). A methane flux transfer function will also be built by integrating modern CH₄ fluxes with local water-table depth along the same nordic transect (Garneau et al., 2009). Those transfer functions will allow the reconstruction of paleohydrological conditions and related methane dynamics that influenced peat aggradations through the Holocene in northeastern Canada. Loss-on-ignition has allowed the determination of sediments bulk density as well as organic and related carbon contents through the cores. LORCA and RERCA supported by ¹⁴C and ²¹⁰Pb have been done to reconstruct the peat accumulation processes integrated with hydroclimatic variability and permafrost development.

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Sphagnum Mosses as Methane Traps in a Boreal Mire

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Sphagnum cuspidatum Hoffm. was recently shown to have methane (CH₄) oxidation capacity due to inhabiting methanotrophic bacteria (Raghoebarsing et al. 2005). This is an interesting finding as peatlands are a major natural source of the strong greenhouse gas CH₄ into the atmosphere. Emissions from *Sphagnum* dominated mires are generally lower than those from *Carex* dominated ones. One reason for this could be the CH₄ oxidation associated to these mosses. According to this postulate the carbon released in decomposition would be efficiently refixed in moss photosynthesis and the moss layer would reduce the flux of CH₄ and carbon dioxide to the atmosphere.

To study the importance of *Sphagnum* as a habitat for CH₄ oxidizers, we addressed the following questions.

1. Is the variation in CH₄ oxidation in *Sphagnum* mainly regulated by the abiotic environment or by the hosting moss species?
2. What is the contribution of CH₄ oxidation in *Sphagnum* to net CH₄ flux from a whole mire to the atmosphere?

The study was carried out at Siikaneva fen in Finland (e.g., Riutta et al., 2007). To answer question 1, we collected the dominant coexisting *Sphagnum* species from hummock, lawn and flark habitats and determined the potential in mosses to oxidize CH₄ using flask incubations and gas chromatography. To answer question 2, we removed *Sphagnum* from selected plots, measured CH₄ flux using chamber technique and used stable isotopes to determine associated processes.

Water level was the key environmental control of methanotrophy in *Sphagnum*. The potential rate to oxidize CH₄ in the top 10 cm of the moss layer was 0.5 to 5 mol m⁻² h⁻¹ in different habitats along the moisture gradient, which is 3 to 4 orders of magnitude higher than the net CH₄ flux to the atmosphere from the same sites. The moss removal could increase the net flux of CH₄ by up to 50%. Our results suggest that CH₄ oxidation in the *Sphagnum* layer is potentially major control for CH₄ release from a boreal fen ecosystem.

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Peat Composition in Cool Temperate Bogs of Different Drainage History

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Oxygen supply in the catotelm of bogs is typically strongly limited. These reducing conditions cause O/C and H/C ratios in the peat to decline with depth whereas the relative C concentration increases. Upon drainage and subsequent oxidation, the decomposition rate is accelerated. A fraction of organic carbon is lost as CO₂. Inorganic compounds accumulate (see Fig. 1) so that the measured ash content in the upper 30 cm is increased by up to 70% relative to lower soil layers. We examined how different drainage histories affected the chemical composition and the ash content of four cool temperate bogs in Switzerland and evaluated whether a relative change in ash concentration is a useful proxy for historical drainage-induced C losses. In all profiles, O/C ratios declined to reach a constant value of around 0.45 in 2 m depth. Ash contents did not follow exactly the same pattern indicating that either: i) these two parameters are influenced by different processes or that ii) organic matter remaining after oxidative peat consumption is chemically more reduced. Calculated C losses based on the relative increase in ash were highly variable, indicating a limited power of this indicator for estimating drainage-induced C losses. Further studies using ¹³C NMR and XPS spectroscopy showed pronounced changes in the functionality of carbon that is related to the conditions for decomposition. The suitability of these chemical peat parameters for estimating C loss is discussed.

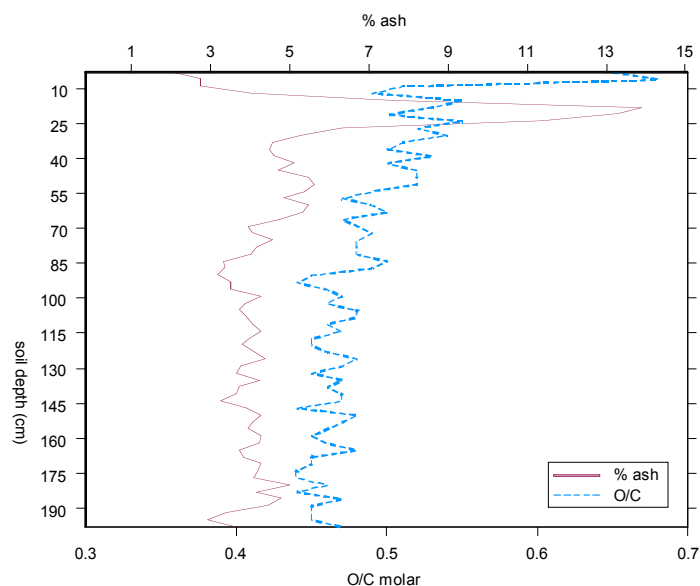


Figure 1: . Changes in ash content and O/C ratio of a drained bog with depth (mean ash content of site Eigenried, peat cores A-C, O/C ratio of peat core B).

Expanding Peatlands in South-Central Alaska: A Response to Glaciers-climate Feedbacks?

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We have observed in the field that many peatlands in the Susitna Basin, south-central Alaska, are expanding. High moisture conditions are needed to promote peatland development and expansion, a regional change toward wetter conditions is likely responsible for the ongoing paludification of these peatlands. However, instrumental climatic data from this region show no increase in precipitation but an increase in temperature (and presumably evaporation) over the last several decades. Since glacier recession has further accelerated since 1988 around the Gulf of Alaska (Arendt et al., 2002), we hypothesize that climatically-induced glacier melting is modifying the local/regional climate, especially air humidity during the growing season, promoting the expansion of peatlands.

To document recent peatland vertical growth and lateral expansion, we collected two long peat cores and twelve 30-cm-long monoliths in 2008 along a 110-m transect from an expanding peatland margin toward the peatland center. Ecohydrologic changes were reconstructed from testate amoebae, plant macrofossils, and pollen assemblages. Macrofossil analysis results from both long cores revealed a change in peatland vegetation from a mesotrophic fen dominated by sedges and brown mosses to a *Sphagnum*-dominated peat bog 30 years ago. However, water table reconstruction from testate amoebae shows an increase in water table. These unusual shifts in peatland development and hydrology (e.g., wet conditions corresponding with the fen-bog transition) imply a recent increase of atmospheric water to these peatlands. Our ongoing lead-210 dating and additional proxy analysis will help us resolve the timing and nature of recent peatland changes. These data, together with glacier history and climate records, will allow us to further test our hypothesis that the increase in glacier meltwater is causing peatland expansion in this region. In contrast to the often assumed desiccation of peatlands under a warmer climate (Tarnocai, 2006), increased air humidity and moisture induced by glacier melting in a warmer climate in high-latitude regions may actually promote peatland growth and expansion, serving as carbon and water sinks, even just temporally.

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Contemporary Exchange of CO₂ and CH₄ in a Temperate Ombrotrophic Bog

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To understand how the terrestrial biosphere will feedback on climate change, it is of crucial importance to collect high resolution long-term data on the greenhouse gas exchange together with environmental variables from different ecosystems. To establish process-based knowledge of the exchange of radiatively active gases such as carbon dioxide (CO₂) and methane (CH₄). One important ecosystem type is northern peatlands, due to the large amount of organic carbon (C) stored in their soils (Gorham 1991).

Here we present more than three years of continuous eddy covariance measurements of the land-atmosphere CO₂ exchange in a south Swedish temperate bog (Fäjemyr), together with one year of automated chamber measurements of the CO₂ and CH₄ exchange. During this period, the bog acted as a small sink for atmospheric CO₂ of -8.7 ± 12.2 (mean \pm SD) g C m⁻² yr⁻¹. However, during the last year there was an extended summer drought period that switched the ecosystem into a net source of CO₂ on an annual basis. According to the parameters of a light response curve, decreased gross primary production was primarily responsible for a decrease in summer-time net CO₂ uptake.

The annual exchange of CH₄ was relatively low compared to other peatlands, ranging 1.1-3.1 g C m⁻² dependent on micro-topographical sub-site. High CH₄ emissions were detected in connection with front systems bringing about rainfall and associated decreases in atmospheric pressure. Taking into account other potential C loss pathways such as C export with water runoff, our data set indicates that the temperate bog being studied here no longer acts as a persistent sink of atmospheric C. Prolonged summer drought periods in the future can turn northern peatlands, which are sensitive to reduced water availability, into significant sources of gaseous C.

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