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Did fires drive Holocene carbon sequestration in boreal ombrotrophic peatlands of eastern Canada?

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A B S T R A C T

Wildfire is an important factor on carbon sequestration in the North American boreal biomes. Being globally important stocks of organic carbon, peatlands may be less sensitive to burning in comparison with upland forests, especially wet unforested ombrotrophic ecosystems as found in northeastern Canada. We aimed to determine if peatland fires have driven carbon accumulation patterns during the Holocene. To cover spatial variability, six cores from three peatlands in the Eastmain region of Quebec were analyzed for stratigraphic charcoal accumulation. Results show that regional Holocene peatland fire frequency was ~2.4 fires 1000 yr^{-1}, showing a gradually declining trend since 4000 cal yr BP, although inter- and intra-peatland variability was very high. Charcoal peak magnitudes, however, were significantly higher between 1400 and 400 cal yr BP, possibly reflecting higher charcoal production driven by differential climatic forcing aspects. Carbon accumulation rates generally declined towards the late-Holocene with minimum values of ~10 g m^{-2} yr^{-1} around 1500 cal yr BP. The absence of a clear correlation between peatland fire regimes and carbon accumulation indicates that fire regimes have not been a driving factor on carbon sequestration at the millennial time scale.

Introduction

Ongoing climate changes affect the ecological dynamics of boreal ecosystems where wildfires play a key role (Bergeron et al., 2010), including the carbon (C) balance of peatlands (Turetsky et al., 2002). Peatlands are frequent in topographic depressions of the boreal and subarctic regions, globally covering 3–4 million km^2 (MacDonald et al., 2006; Yu et al., 2010). Due to cool, humid, nutrient-poor and acidic conditions that restrict decomposition, ombrotrophic peatlands sequester organic C and expanded vertically and laterally over millennia (Korhola, 1994; Tolonen and Turunen, 1996; Korhola et al., 2010). As a result, the global northern peatland C stock, which started accumulating after the Last Glacial Maximum, presently contains ~547 Pg (range: 473–621 Pg), constituting approximately a third of global soil C (Yu et al., 2010). Peatland fires influence local C dynamics by a release of C to the atmosphere through combustion, estimated at 2.5–3.2 kg m^{-2} per fire (Pitkänen et al., 1999; Turetsky et al., 2002). In addition, postfire C loss is generally important due to a delay in vegetation re-establishment (Wieder et al., 2009).

In Canadian boreal zones, a potential increase of fire frequency and area burned during the next decades (Flannigan et al., 2005; Bergeron et al., 2010) may force peatlands and upland areas to switch from net C sinks to sources to the atmosphere. The negative effect of recurrent fires on long-term peat and C accumulation has been established for different peatland types and regions around the globe, yet research has been concentrated in boreal western and central Canada (e.g. Kuhry, 1994; Robinson and Moore, 2000; Turetsky et al., 2002; Camill et al., 2009). In these regions, climate-driven increases in fire frequency or severity may force peatlands to switch from net sinks to sources in the course of the 21st century (Turetsky et al., 2002; Wieder et al., 2009). Whereas in western Canada forested peatlands have developed under a dry continental climatic regime, dominance of open bogs with relatively high water tables in the more humid climate of eastern boreal Canada may inhibit differential fire and C accumulation dynamics (Payette et al., 1989; Payette and Rochefort, 2001). In the Eastmain region, peatlands have accumulated considerable amounts of C during the last ~7000 yr, regionally averaging 91 kg m^{-2} at a mean rate of 16.2 g m^{-2} yr^{-1} (van Bellen et al., 2011a). C accumulation rates are given here as “apparent” rates,

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representing the remaining accumulated C actually present in the peat sequence, instead of “real-time” historical accumulation rates; the difference between these two rates is due to long-term decomposition of peat under anoxic conditions.

Peatland hydrology and vegetation strongly influence the potential for fire propagation, whereas the amount of peat consumed varies with local and regional humidity conditions (Zoltai et al., 1998). The highly variable spatial patterns of moisture conditions within and among peatlands are closely linked to surface microtopography (i.e. hummocks and hollows) and vegetation composition. Hence, interactions between vegetation and hydrology are important factors on burning potential (Higuera et al., 2009). The presence of trees and shrubs in peatlands positively influences fuel continuity and it is therefore associated with more frequent fires (Camill et al., 2009), and forested bogs may be more susceptible to burn as water tables are generally low. Although burning in wet, open peatlands is evident under drought conditions (Fig. 1) open peatlands often remain unaffected by fire, especially when local water tables are high and trees are sparse (Hellberg et al., 2004). As a result, fire frequencies in open peatlands are generally lower than those of adjacent forest stands (Kuhry, 1994; Zoltai et al., 1998; Camill et al., 2009).

Here, we present a study on the Holocene patterns of fire and C sequestration based on the quantification of stratigraphic charcoal from three ombrotrophic peatlands in the Eastmain region in boreal Quebec, northeastern Canada. Specifically, we aimed to estimate if peat fires have driven long-term variations in C accumulation. Ombrotrophic peatland fire regimes, ecohydrological change and C sequestration are directly or indirectly linked to climate conditions, therefore we considered variations in climate regimes during the Holocene. Given the evident negative influence of individual fires on peatland C sequestration (Wieder et al., 2009), we hypothesized that if Holocene fire regimes had driven long-term C sequestration, this would be manifested by a negative relationship between fire regimes and C accumulation rates (cf. Kuhry, 1994). As shown in the study by Kuhry (1994) in western boreal Canada, we verified correlations between fire frequency and C accumulation rates, as well as between peatland fire-associated cumulative charcoal and C accumulation rates. This study provides an understanding of Holocene dynamics in peatland fire regimes in a relatively unexplored region. Besides, additional knowledge on the influence of historical fire regimes on C sequestration may also clarify the role of unforested boreal peatlands in future C cycling.

Study region

Three pristine peatlands were studied, Lac Le Caron (LLC), Mosaik (MOS) and Sterne (STE), located in the Eastmain river watershed (51°50′–52°20′N/75°00′–76°00′W) (Fig. 2). Regional mean annual temperature is -2.1 ± 0.2°C (January: -22.0 ± 0.5°C; July: 14.6 ± 0.2°C) and mean precipitation is 735 ± 12 mm, of which about one third falls as snow (interpolated means and standard errors of 1971–2003 NLWIS data; Hutchinson et al., 2009). Forest fire regimes are among the most important in eastern Canada with actual fire cycles (i.e. the time required to burn an area equivalent to the area studied) of 90–100 yr (Payette et al., 1989; Mansuy et al., 2010). Regionally, all large fires may be assumed wildfire as human activity is highly restricted. Figure 1 shows an example of an Eastmain peatland burning pattern. A complete description of peatland characteristics can be found in van Bellen et al. (2011a).

Methods

Fieldwork

From each of the three peatlands two coring sites were selected at opposing sections within each peatland (Fig. 2). To obtain records with a sufficiently high temporal resolution, we aimed to extract cores of at least 1.5 m in length, nearby the forest–peatland boundary, which was identified by absence/presence of a surface *Sphagnum* cover and an organic horizon thickness of >40 cm (Commission Canadienne de Pédologie, 1998). As the slope of the peatland basin was highly variable between sites, the distance between coring location and peatland–forest limit varied between 12 and 132 m. Coring was performed using a box corer (10×10 cm width) to sample the upper 1 m and Russian peat samplers (4.5- to 7.5-cm diameter) for deeper horizons. Monoliths were wrapped in plastic, transferred to polyvinyl chloride tubes and stored at 4°C until analysis.

Charcoal fragment and peat C quantifications

Prior to specific treatment, cores were sliced into contiguous 1 cm subsamples in the laboratory. From each slice, 2 cm^3 was retained for macrocharcoal analysis, assumed large enough to provide replicable data (Carcaillet et al., 2001). The subsample was soaked for at least 14 h in 5% KOH and carefully rinsed through a 355-μm sieve. Material

Figure 1. Eastmain region peatland after fire. This peatland was not a study site. Photo by Hydro-Quebec.