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Stable carbon and oxygen isotopes in *Sphagnum fuscum* peat from subarctic Canada: Implications for palaeoclimate studies

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ABSTRACT

Stable carbon and oxygen isotope ratios in single plant components in Sphagnum peat have a good potential to reveal environmental changes in peat archives. Two peat profiles, covering the past ~6000 years, and a Sphagnum hummock from a discontinuous permafrost area in west central Canada were studied in order to evaluate the effect of decomposition rate on isotope records and to assess which plant components are most suitable for climate reconstructions. The stable isotope values from the most recently forming Sphagnum tissues were compared with observational climate data to study the impact of variations in temperature and precipitation on the peat isotopes. Our results show that there is high correlation between $\delta^{13}C$ values in α-cellulose isolated from *Sphagnum fuscum* stems and summer temperatures, whereas $\delta^{18}O$ in the plant tissues is controlled by several factors, such as summer precipitation, summer temperature and evaporation. According to our results, decomposition as derived from C/N values and colorimetry does not seem to affect the oxygen and carbon isotope values of α-cellulose from *Sphagnum fuscum* peat significantly. There is, however, a (quasi-) constant offset between the isotope values of branches and stems and between whole plant material and α-cellulose, which makes it crucial to select single moss-fractions when past climate and environmental changes are to be derived from the isotope record.
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1. Introduction

Peatlands of the northern hemisphere are possible sources of vast quantities of greenhouse gases to the atmosphere and can thus enhance predicted temperature increases in high latitudes through positive feedback mechanisms (Schuur et al., 2009). The role of variations in temperature and moisture in permafrost thawing and following decay of soil organic matter will be most pronounced within the discontinuous permafrost zones (Prowse and Ommanney, 1990; Turetsky et al., 2007). On the other hand, the response of vegetation migration patterns to environmental changes can lead to potential negative feedback mechanisms by increasing evapotranspiration and latent heat loss (Foley et al., 2003) through poleward advance of boreal ecotones. One way to improve our understanding of Arctic climate and its feedback mechanisms is to analyse past environmental changes from peat archives with continuous Holocene records, where anthropogenic imprints are sparse. Plants growing in ombrotrophic bogs assimilate only meteoric water (Charman et al., 1999), containing an isotopic signal that reflects the climate from their growth period and the source water isotopic composition. During the last decade several studies have demonstrated the potential of stable isotopes ($\delta^{18}O$, $\delta^{13}C$, $\delta^{2}H$) in peat mosses as proxies for environmental change, such as temperature, humidity and/or precipitation shifts (Ménot-Combes et al., 2002; Sharma et al., 2004; Loader et al., 2007; Lamentowicz et al., 2008; Daley et al., 2009; Moschen et al., 2009; Loisel et al., 2009). Still, the interpretation of the isotopic composition in peat in terms of environmental changes is complicated by the varying time resolution of peat samples due to uneven growth rates, species-specific differences, poorly known biochemical pathways in plant tissues, and signal preservation in decomposed peat.

Differences in decay rates between plants and species in same environments (Blackford and Chambers, 1993; Charman et al., 1999) could lead to systematic errors for the preservation of the isotope signal in peat profiles (Loader et al., 2007). The minimum sample size required for isotope analysis limited earlier moss studies to the use of

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bulk peat, but recent developments in mass spectrometry have enabled analyses of single plants and isolated moss components (Loader et al., 2007). *Sphagnum fuscum* is a favourable species for single plant studies for several reasons. It inhibits competition from other species by building thick mats high above the groundwater table and creating acidic, relatively dry hummocks (Lindholm, 1990; Rydin and Jeglum, 2006). It also has high accumulation rates due to good preservation although the productivity is lower than for species growing in hollows, e.g. *S. cuspidatum* (Gunnarsson, 2005). Furthermore, *S. fuscum* is a common moss species at high latitudes in North America, Fennoscandia and Asia (Lindholm, 1990; Andersson et al., 1995), which is a benefit for pan-Arctic environmental studies.

In previous stable isotope studies, the preparation of peat samples has mainly followed methods used for vascular plants. Most of the tree-ring studies have traditionally used the cellulose fraction of plant material for isotope analyses. An interlaboratory comparison of cellulose preparation methods suggested that the use of α-cellulose (alkali insoluble fraction) is preferable to holocellulose (Boettger et al., 2007). The necessity of cellulose preparation is also debated, as the procedure is time consuming and requires special laboratory equipment (Borella et al., 1998; Ménot and Burns, 2001; Cullen and Grierson, 2005). Whole plant material from modern *Sphagnum* samples has been used successfully for palaeoclimatic carbon isotope studies (Ménot and Burns, 2001; Loader et al., 2007; Skrzypek et al., 2007a). However, different decay rates of e.g. lipids and cellulose fractions in whole plants could influence results from palaeosamples, and different decay rates of plant components (branches and stems) may lead to systematic errors caused by the isotopic offset between them (Loader et al., 2007).

Our study focuses on the question which climate parameters show the highest correlation with oxygen and carbon isotopes in different fractions of *Sphagnum fuscum* and on methodological uncertainties, such as isotope fractionation by different plant components and the climate signal preservation in peat that has formed during the Holocene. The study includes stable isotope ($\delta^{13}C$ and $\delta^{18}O$) analyses from whole plant and cellulose fraction of *S. fuscum* stems and branches, as well as analyses of peat decomposition by colorimetric (humic substances) and geochemical (C/N) methods. Our research is structured around three key questions:

- What is the impact of peat decay on the stable isotope composition of *Sphagnum fuscum* peat?
- Is cellulose purification from *Sphagnum* mosses necessary for stable isotope studies and which *Sphagnum* components are most suitable for palaeoclimate reconstructions?
- Which climate parameters can be reconstructed by the analysis of oxygen and carbon isotopes in peat?

2. Study area

The material consists of two peat profiles and a hummock sampled within the discontinuous permafrost zone (DPZ) in northern Saskatchewan, Canada (Fig. 1). In the DPZ, most of the water bodies and fens are not underlain by permafrost unlike peat plateaux and palsas (Zoltai, 1995), where the seasonally unfrozen active layer has a thickness from a few tens of centimetres to up to a couple of meters (Davis, 2001). The peat profiles used for our study, S52 (59°52′ N, 104°12′ W; 395 m elevation) and S53 (59°55′ N, 104°13′ W; 394 m), were collected in 1993 in the peatlands southeast of Selwyn Lake. S52 was cut from a forested peat plateau and profile S53 in a peat plateau/palsa complex. The observed vegetation at the study sites consisted of trees (*Picea mariana*, *Larix laricina*), shrubs (*Chamaedaphne calyculata*, *Ledum* sp., *L. groenlandicum*, *Rubus chamaemorus*, *Oxycoccus palustris*, *Vaccinium uliginosum*, *V. vitis-idaea*), mosses (*Sphagnum fuscum*, *S. rubellum*, *S.* spp., *Drepanocladus* sp.) sedges (*Carex* spp., *Eriophorum* sp., *Equisetum* sp.) and unidentified lichen species. In 2005, field work was carried out at Misaw Lake *c.* 90 km east of Selwyn Lake. The *Sphagnum fuscum* hummock ML3 (59°52′ N, 102°34′ W; 390 m) collected in that year was included in the study. The vegetation around the hummock consisted of *Picea mariana*, *Betula glandulosa*, *Ledum groenlandicum*, and *Vaccinium vitis-idaea*.

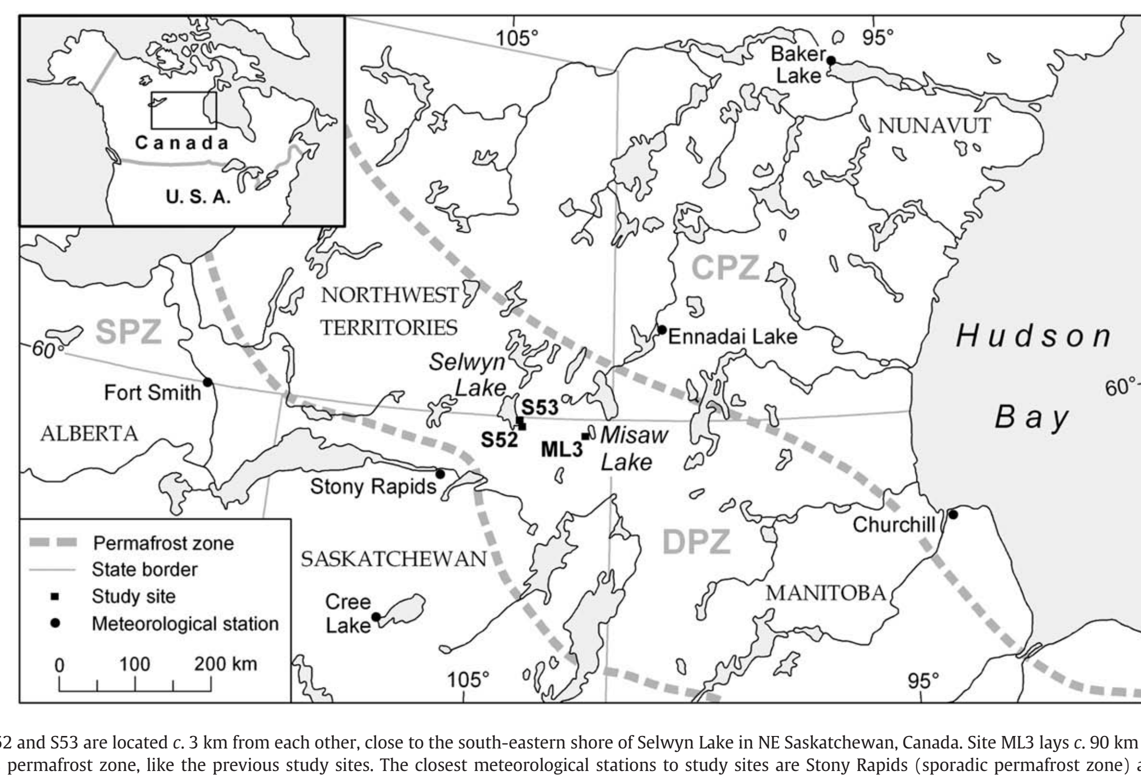

Fig. 1. Sites S52 and S53 are located *c.* 3 km from each other, close to the south-eastern shore of Selwyn Lake in NE Saskatchewan, Canada. Site ML3 lays *c.* 90 km east of S52 in the discontinuous permafrost zone, like the previous study sites. The closest meteorological stations to study sites are Stony Rapids (sporadic permafrost zone) and Ennadai Lake (continuous permafrost zone). Present permafrost zones: SPZ = sporadic, DPZ = discontinuous and CPZ = continuous permafrost zone after Zoltai (1995).

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