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HIGH LATITUDE PEAT DEPOSITS IN CANADA AND RUSSIA AS CLIMATE ARCHIVES

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SUMMARY

Stable isotopes derived from peat archives are relatively new proxies for palaeoclimate variation. We have studied subarctic climate variability from peat archives in Canada and Russia by stable carbon and oxygen isotopes in α-cellulose isolated from stems of a single species, *Sphagnum fuscum*. Isotope ratios vary depending on source values and climatically controlled isotope fractionation during photosynthesis and evaporation. The climate reconstruction was supported by plant macrofossil and humification analyses and extensive dating by ^{210}Pb and AMS ^{14}C. Modern values were calibrated against meteorological observations in the studied regions. Our results confirm the potential of stable carbon and oxygen isotope ratios derived from single moss species for climate reconstruction and quantification of temperature variation.

KEY WORDS: **Stable isotopes, macrofossil, *Sphagnum fuscum*, climate, subarctic**

INTRODUCTION

Vast peatland areas have developed in northern America and Eurasia since the last glaciation, either due to terrestrialization (lake infilling) or paludification (lateral expansion over former upland areas). Besides local settings, temperature and (soil) moisture conditions are essential factors for peat accumulation that is vigorous in wet temperate, boreal and subarctic regions. As the global warming is amplified in the arctic (Miller et al., 2010), it is important to improve our understanding of climate variation and feedback mechanisms in the northernmost environments. Palaeoclimate records from peat archives provide continuous Holocene records: plant macrofossil assemblages reflect fluctuations in hydrology and permafrost dynamics (Sannel and Kuhry, 2008) and stable isotope studies of plants reflect changing palaeotemperature and/or moisture conditions (Daley *et al*., 2010; Kaislahti Tillman *et al*., 2010a). Besides variation among species (Brenninkmeijer *et al*., 1982), isotope ratios in plants depend on source values and climatically controlled isotope fractionation during photosynthesis and evaporation. Within a species, the isotope contents are known to differ by several parts per mil in stems and branches

(Loader *et al*., 2007; Kaislahti Tillman *et al*., 2010b). As mosses lack water regulation by stomata, the grade of filling of hyaline (water reservoir) cells is regarded as the main mechanism controlling diffusion of atmospheric CO_2 into photosynthetic cells, where carbon isotope fractionation is enzymatically controlled by kinetic (temperature dependent) effects during carboxylation (Rice, 2000). Stable oxygen isotopes are not fractionated during the uptake to plants but display the pathway of meteoric water from moisture source to the plants, where heavier ^{18}O isotopes are enriched (relative to ^{16}O) during photosynthesis partly due to increased evaporation (Zanassi and Mora, 2005).

MATERIALS AND METHODS

We have studied climate variability from peat archives in subarctic Canada and Russia by plant macrofossil and stable isotope analyses. Stable carbon and oxygen isotope ratios ($\delta^{13}C$, $\delta^{18}O$) were derived from the α-cellulose fraction in stems of *Sphagnum fuscum*; a drought tolerant species with circum-Arctic distribution in ombrotrophic environments (mainly fed by meteoric water) that has high decay resistance, high accumulation rates and a high capacity to out-compete other species (Gunnarsson, 2005; Rydin and Jeglum, 2006). Plant macrofossils were identified with a stereo binocular (25-40X magnification) and *Sphagnum* species by leaf morphology under a light microscope (100-400X magnification). Peat accumulated in recent decades was dated by ^{210}Pb-, ^{137}Cs- and so called "post-bomb" ^{14}C -dating, and older sections by AMS-^{14}C dating. The effect of decomposition in palaeorecords was tested by a comparison of stable isotope ratios with C/N ratios and colorimetric humification values. Modern stable isotope values were calibrated against meteorological observations in the studied regions. A statistically significant relationship between summer temperatures and $\delta^{13}C$ values was used to reconstruct palaeo-temperatures. Low correlations between isotope proxies and observed precipitation hampered a reliable quantitative reconstruction of moisture conditions at all sites. However, some conclusions could be made based on a combination of macrofossil analysis, peat humification and $\delta^{18}O$ records.

RESULTS

The results show that isotope signals of α-cellulose were well preserved on millennial time scales. In central Canada, July temperatures were the main control on $\delta^{13}C$ variation. Reconstructed temperatures ranged 6.5^0C ($\pm 2.3^0C$) over the last 6.2 ka with thermal maxima around 4.3 ka BP and 3.1 ka BP of *c*. 3°C warmer temperatures than at the end of the 20th century (Fig. 1). Between *c*. 2.5 and 1.2 ka BP, 3-4°C lower values were found compared to the period corresponding to the Mediaeval Climate Anomaly, when temperatures were close to modern values. The general cooling tendency of the last millennium is indicated by a rapid drop by *c*. 4°C around 0.4 ka BP. The latter part of the so called Little Ice Age was not recorded because of a hiatus in our proxy record. 20th century temperatures were characterized by an increasing but fluctuating trend. Despite the differences in temporal resolution in peat archives and lake sediments, temperature variation had similar amplitudes on the centennial scale compared with chironomid records from central Canada. Before *c*. 4.3 ka BP and from *c*. 2.5 ka BP forward climate was relatively dry, except (local) wetter periods around *c*. 1.7 ka BP, 1.3 ka BP and 0.4 ka BP that plausibly are the result of more humid southerly air-masses periodically decreasing the influence and southwards fluctuations of the Arctic front (Kaislahti Tillman *et al*., 2010a)

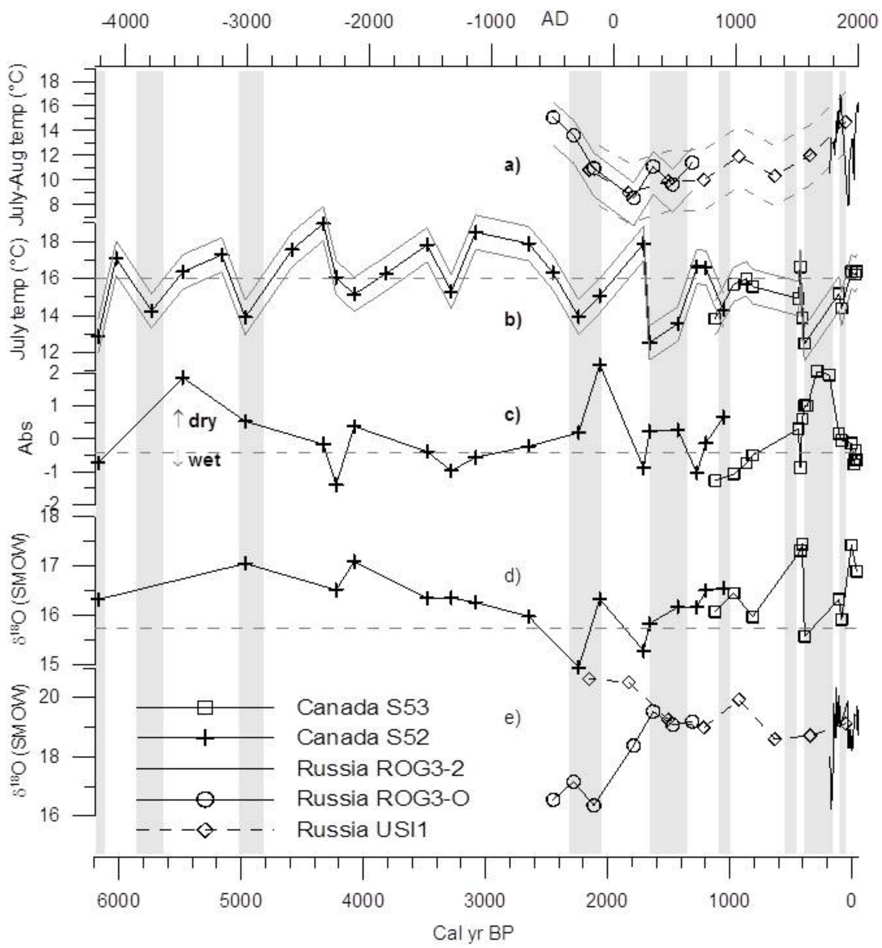

Fig. 1 From the top: a) reconstructed July-August temperatures in Russian tundra (Rogovaya peat plateaus; ROG3-2 and ROG3-O) and the northern taiga (Usinsk mire USI1); b) reconstructed July temperatures in central Canada (Selwyn Lake peat plateau; S52, S53); c) Absorbance of bulk peat (humification index) values as a proxy of dry-wet shifts in the surface moisture in Canadian sites; stable oxygen isotope time series from d) Canadian and e) Russian peat profiles, which reflect temperature and/or moisture conditions. Temperature reconstructions by $\delta^{13}C$ values are based on the α-cellulose fraction in stems of *Sphagnum fuscum*, similarly to $\delta^{18}O$ time series. The limits of error estimates are marked by grey lines and cold periods (relative to present temperatures) in the Canadian time-series by shaded bars.

Preliminary results from north-eastern European Russia show that $\delta^{13}C$ variations had highest correlation with July-August temperatures. Because *Sphagnum fuscum* was not present throughout the longest peat profiles, our temperature reconstruction (Fig. 1a and b) was composed of several records with varying resolution from sites in tundra peat plateaus and the northern taiga,. The variation in reconstructed summer temperatures was 9.0^0C ($-2.3^0C/+1.2^0C$) in decadal scale (tundra site) and *c*. 6.5^0C in centennial/millennial scales (tundra and northern taiga sites). There is macrofossil evidence of local wetter conditions in the tundra and northern taiga peatland sites before *c*. 2.2 ka (Oksanen et al., 2001; 2003), followed by drier conditions as indicated by *S. fuscum* dominance in both peat archives. Therefore, diverging $\delta^{18}O$ records between 2.5 ka and 1.7 ka reflect possibly regional heterogeneity in precipitation patterns with different $\delta^{18}O$ source values and/or different local evaporation rates.

CONCLUSIONS/DISCUSSION

In our study material, temperature controlled isotope fractionation is the major control of stable carbon isotope variability in the α-cellulose component of *Sphagnum fuscum* stem tissues. The $\delta^{13}C$ based temperature reconstruction shows similarities with other proxy records, despite the difficulties with age controls and differences in temporal resolution. For reliable temperature predictions, it is important that calibration sets cover a large range of temperatures. Longer time-series could be obtained if additional species were studied and used for calibration. High resolution stable carbon isotope time series show good potential for reconstructions of rapid climate changes. The climatic control of moisture can change over different time periods depending on the direction of dominating air-mass trajectories, which result in different source $\delta^{18}O$ values and amounts of evaporative enrichment. Surface wetness reconstruction by other proxies, such as macrofossil, humification, or testate amoeba analyses, is needed for interpretation of stable oxygen isotope time series.

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