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Research paper

Response of plant communities to climate change during the late Holocene: Palaeoecological insights from peatlands in the Alaskan Arctic

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ABSTRACT

High-resolution plant macrofossil records were examined alongside pollen, micro- and macro-charcoal, and testate amoeba data to elucidate the dynamics of two permafrost peatlands in the northern foothills of the Brooks Range, Alaskan Arctic. The vegetation dynamics of these two peatlands were driven by autogenic processes reflecting the development trajectory of the peatlands towards ombrotrophic status, and allogenic climate change. We observe an increase in shrub pollen and macrofossils (e.g. Ericaceae, *Betula nana*) during two Late Holocene warm episodes and in recent decades. Pollen data suggest that regional forest cover also responded to temperature increase since ca. 1950 CE. An increase of *Picea* pollen (up to 13%) in the upper part of peat profile is probably associated with long distance pollen transport from populations of *Picea mariana* and *Picea glauca* located at the southern foothills of the Brooks Range. Relatively small amount of micro- and macrocharcoal in the two profiles indicates little fire activity around the sampling sites over the last ca. 2000 years, which is in agreement with regional findings. The lack of surface and groundwater influence under prolonged warmer/drier condition can allow *Sphagnum* to expand in Arctic peatlands. Cold climatic conditions might have been detrimental to *Sphagnum* populations, that were replaced by *Carex* spp. and other vascular plants owing to wetter conditions in the peatland.

1. Introduction

High-latitude ecosystems have experienced more pronounced climate warming than other parts of the globe in recent decades, and are projected to continue to warm rapidly in the future (IPCC, 2013). This rapid warming will lead to plant range shifts, changes in species composition, and variation in peat accumulation rate and carbon sequenstration (Elmendorf et al., 2012; Yu, 2012; Kuhry et al., 2013). Shrub-dominated communities (e.g. *Betula, Salix* and *Alnus*) are increasing in cover and height (Myers-Smith et al., 2011; Ropars and Boudreau, 2012), and fires are becoming more frequent in high-latitude ecosystems (Rocha et al., 2012; Young et al., 2016). The expansion of shrubs restricts the growth of other plant species by limiting light availability and exacerbating the frequency and intensity of fire regime. To date, most data on the response of plant communities to recent warming come from observational and experimental studies (e.g. Callaghan et al., 2004; Hollister et al., 2005; Post et al., 2009; Elmendorf et al., 2012; Oberbauer et al., 2013; Edwards and Henry, 2016), with comparatively few studies examining changes on centennial to millennial temporal scales (e.g. Oswald et al., 2003; Gajewski, 2015; Teltewskoi et al., 2016; Treat et al., 2016). In addition, there are major limitations in our understanding of the tolerance of tundra species to fire (Racine et al., 2004; Higuera et al., 2011; Bret-Harte et al., 2013). Therefore, detailed long-term palaeoecological studies of permafrost peatlands are needed to improve understanding of relationships between climate, vegetation, fire, and hydrology, with implications for elucidating the response of high-latitude vegetation to climate warming (Bigelow et al., 2003; Gao and Couwenberg, 2015; Swindles et al., 2015a; Fritz et al., 2016).

Peatlands in the Arctic are important archives of palaeoenvironmental data owing to their sensitivity to climatic and hydrological change (Turetsky et al., 2002; Lamarre et al., 2012). Rising temperatures have driven partial or complete thawing of permafrost peatlands in many arctic regions (Biskaborn et al., 2015). Northern Alaska has

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experienced rapid climate warming during the twentieth century, degradation of permafrost peatlands and deepening of the active layer (Raynolds et al., 2014). Furthermore, climate models project continued marked temperature increases in the near future in this region (IPCC, 2013). Previous palaeoecological studies conducted in the Arctic including Alaska (Oswald et al., 2003, 2014) and Siberia (Minke et al., 2007; Zibulski et al., 2013; Teltewskoi et al., 2016) indicate that the nature of the soil substrate and microrelief play important role on how tundra environments respond to climate change.

In this study we present the first multiproxy late Holocene (the last 2000 years) palaeoecological dataset (plant macrofossils, pollen, testate amoebae, charcoal) from peat profiles in the Toolik region, Alaskan Arctic (northern foothills of the Brooks Range). We use these data to examine the long-term dynamics of plant communities in arctic peatlands and potential drivers of change. We evaluate the influence of changes in climate and anthropogenic disturbances versus autogenous succession in the development of arctic plant communities. We focus on the late Holocene because this period contains several phases of marked climate change (PAGES 2k Consortium, 2013). During the time covered in this study, warm periods such as the Roman Period and Medieval Climate Anomaly were separated by cold intervals (Migration Period and the Little Ice Age). We hypothesize that during past warm climatic episodes moss and vascular plant-dominated vegetation communities were replaced by shrub-dominated communities. In addition, we hypothesize that a similar shift is observed in recent decades related to rapid climate warming.

2. Study sites

Our study area is located in northern Alaska, close to the northern foothills of the Brooks Range, near the Toolik Field Station run by the University of Alaska Fairbanks (Fig. 1). The Toolik Lake area (68° 37′ N, 149° 32′ W) was deglaciated about 10,000 cal yr BP (Hamilton, 1986). The Toolik landscape is dotted with small glacial lakes, kames, and moraines. Elevations range from about 670–850 m asl. The climate of the region is continental arctic with mean monthly temperatures ranging from −22.5 °C (January) to 11.2 °C (July), and annual precipitation of ca. 250 mm over the period 1989–2007 (Environmental Data Center Team, 2017, EDC, https://toolik.alaska.edu/edc/about/conditions_of_use.php.). The vegetation in wetter habitats at our sampling sites is dominated by *Sphagnum* spp., *Tomentypnum nitens*, *Paludella squarrosa*, *Carex* spp., *Andromeda polifolia, Salix reticulata* and *Betula nana*. Drier habitats are characterised by *Betula nana, Dryas octopetala, Salix* spp., *Empetrum nigrum, Polygonum bistorta, Rubus chamaemorus, Aulacomium turgidum,* and *Hylocomnium splendens.* For further information on the contemporary plant communites at Toolik refer to Walker et al. (1994).

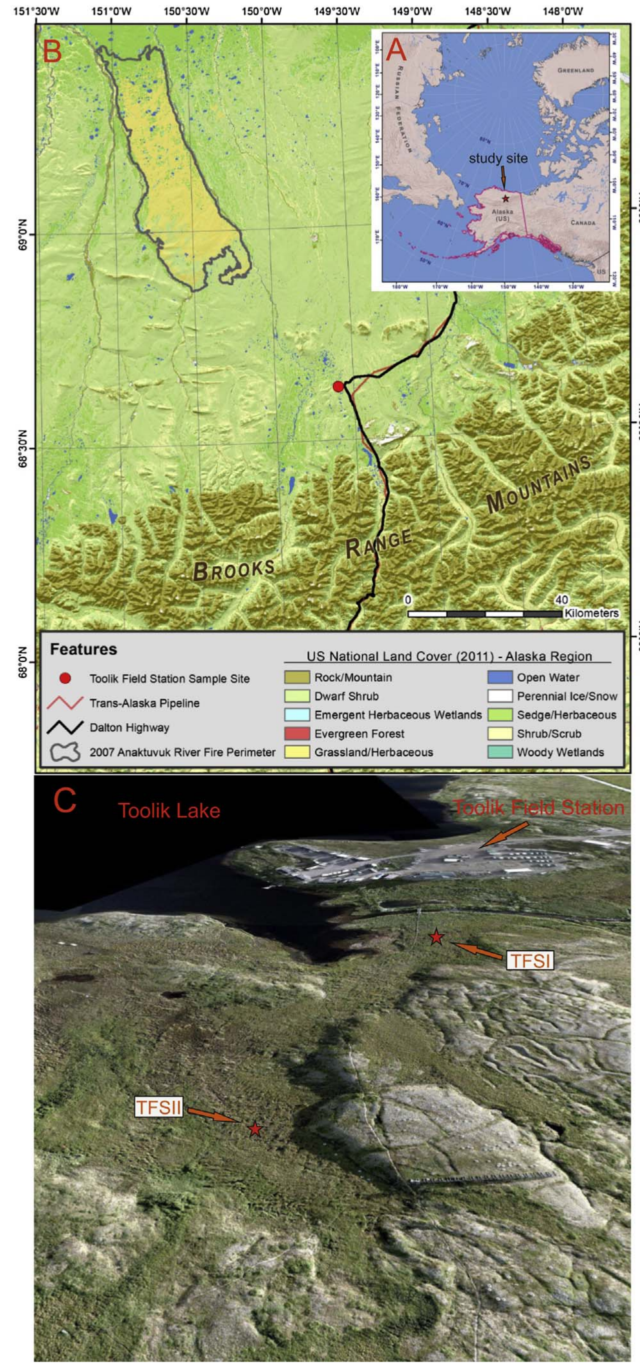

Fig. 1. Map showing locations of the two study sites in the Toolik region.
A) Arctic setting;
B) Regional setting; Fire occurred in 2007.
C) Geobotanical view of sampling sites (based on Vierling et al., 2013);

3. Material and methods

3.1. Peat sampling and chronology of the profiles

Two short peat monoliths (8 × 8 cm), TFSI (45 cm long) and TFSII (50 cm), were sampled from sampling locations 290 m apart. The monoliths were taken from the thickest peat layer in a small hummock microform in each location. Our excavation shows that peat formed directly over bedrock in both locations. The peat profiles were wrapped in plastic film and sent by courier to the laboratory in Poznań. In the laboratory the monoliths were unpacked, cleaned and sliced into 1-cm slices using a scalpel.

Four AMS (Accelerator Mass Spectrometry) radiocarbon dates on hand-picked plant macrofossils and one bulk AMS data were used to provide chronology for TFSI. Five AMS dates on macrofossils were carried out for TFSII (Appendix A). Radiocarbon dating was undertaken at the Poznań Radiocarbon Laboratory. The calibration of the radiocarbon dates and the construction of the age depth models were performed with OxCal 4.1 software (Bronk Ramsey, 2009) and the IntCal13 curve (Reimer et al., 2013) applying a P_Sequence function with a k parameter of 1 cm^{-1} and 1-cm resolution. Distinct changes in the peat composition, which might indicate a change in accumulation rate, were introduced using the "boundary" command (Fig. 2). The modelled ages are expressed as calendar years BCE (*Before Common Era*)/CE (*Common Era*).

Palaeoecological data presented in this paper are compared to palaeoclimate compilations from Arctic and North America (PAGES 2k Consortium 2013).