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Hydrological dynamics and fire history of the last 1300 years in western Siberia reconstructed from a high-resolution, ombrotrophic peat archive

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ABSTRACT

Siberian peatlands provide records of past changes in the continental climate of Eurasia. We analyzed a core from Mukhrino mire in western Siberia to reconstruct environmental change in this region over the last 1300 years. The pollen analysis revealed little variation of local pine-birch forests. A testate amoebae transfer function was used to generate a quantitative water-table reconstruction; pollen, plant macrofossils, and charcoal were analyzed to reconstruct changes in vegetation and fire activity. The study revealed that Mukhrino mire was wet until the Little Ice Age (LIA), when drought was recorded. Dry conditions during the LIA are consistent with other studies from central and eastern Europe, and with the pattern of carbon accumulation across the Northern Hemisphere. A significant increase in fire activity between ca. AD 1975 and 1990 may be associated with the development of the nearby city of Khanty-Mansiysk, as well as with the prevailing positive Arctic Oscillation.

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Introduction

Northern hemisphere peatlands are important archives of past environmental change and sinks of carbon (Charman, 2002; Loisel et al., 2014). However, climate change and human impacts (e.g., wetland drainage and nutrient deposition) trigger increased emission of this stored carbon into the atmosphere (Payne et al., 2013; Ward et al., 2013). Given these ongoing stressors, there is an urgent need to better understand the various processes involved in peatland dynamics (Dise, 2010; Loisel and Yu, 2013). Paleoenvironmental approaches provide a useful perspective on the present state and long-term history of peatlands (Seddon et al., 2014), and the application of coupled biotic and abiotic proxies enables a detailed reconstruction of climate change, peatland ecosystem development, and changes in the surrounding landscape (Gałka et al., 2013).

The last millennium is a critical period for paleoenvironmental study, as it features both climatic variability, such as the Medieval Warm Period (MWP) and the Little Ice Age (LIA), and increasing anthropogenic impacts leading up to the dramatic increases in pollution and global temperatures observed over the last 200 years (Jones and Mann, 2004). Peatland ecosystems experience various types of anthropogenic and natural disturbances, including wetland drainage, forest management, and fire (Dise, 2010). The response of peatlands to disturbance and climate change has been well studied in Europe (Lamentowicz et al., 2008, 2011; van der Knaap et al., 2011), but the paleoecology of Siberian bogs remains largely unexplored.

The hydrological dynamics of Siberian peatlands over the last millennium are of particular interest, and testate amoebae, protists that are abundant in peatlands and sensitive to hydrological conditions, can be used as a reliable proxy for the quantitative reconstruction of past variability in water tables (Hendon and Charman, 2004; Blundell et al., 2008; Booth et al., 2008; Turner et al., 2014). However, while some research has explored the ecology and taxonomy of testate amoebae in Siberian bogs (Muller et al., 2009; Kurina et al., 2010; Bobrov et al., 2013), modern calibration studies have not been carried out in this region. Such calibration data sets for testate amoebae are urgently needed so that this proxy can be utilized for the reconstruction of past hydrological variations in western Siberia.

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Several analyses of Siberian peatlands have focused on carbon accumulation (Lapshina et al., 2001; Turunen et al., 2001; Borren et al., 2004; Beilman et al., 2009; Lapshina and Plogova, 2011), but few peatland studies in this region have generated paleoecological inferences (Liss et al., 2001; Pitkänen et al., 2002; Kremenetski et al., 2003; Peregon et al., 2007a, 2007b; Bobrov et al., 2013). This is in contrast to work in northwest Europe and North America, where a large number of high-resolution, multi-proxy studies have been performed in peatlands (Blundell and Barber, 2005; Booth et al., 2006; Swindles et al., 2007; Kaislahti Tillman et al., 2010; Turner et al., 2014). The lack of such studies in Siberia is unfortunate, as Siberian peatlands cover much larger areas than in other parts of Eurasia. Moreover, paleoenvironmental records from Siberian peatlands have the potential to improve our understanding of past changes in both the continental climate of Eurasia and pristine vegetation that no longer exists in Europe (Solomeshch, 2005).

Charcoal records from peatlands have been used to reconstruct past fire activity in Europe (Sillasoo et al., 2011; Gałka et al., 2013) and North America (Lavoie and Pellerin, 2007), but only limited research of this type has been carried out in Siberia (Turunen et al., 2001), despite the global importance of peatland fires (Turetsky et al., 2015). It is believed that during the last decade, burning has increased in Siberia due to the prevailing positive Arctic Oscillation (Balzter et al., 2005). This relationship can only be verified with a paleoecological approach, since mapped fire data and instrumental weather data cover only short time scales. Over longer intervals, increased fire activity may be related to the prolonged drought events that are recorded by hydrological changes in peatlands. Charcoal data have not been regularly compared to quantitative paleohydrological reconstructions (Tweiten et al., 2009). Nevertheless, the study by Marcisz et al. (2015) showed that a coupled analysis of charcoal and testate amoebae could improve our understanding of past droughts and heat waves over long temporal scales.

In this study, we apply three methodological approaches that previously have not been used together in Siberia. (i) A testate amoebae transfer function was used for a quantitative water table reconstruction; (ii) pollen and plant macrofossils were used to reconstruct vegetation history; and (iii) a charcoal record was used to infer past fire activity. The integration of these proxies allows us to explore the response of boreal peatlands, forest communities, and fire activity to climate change. This research focus aligns well with the *PAGES–Asia2k* research program (Ahmed et al., 2013). A modern calibration study also improves our understanding of testate amoebae ecology in the boreal region of Siberia.

Study site

The Mukhrino mire is located on the eastern bank of the Irtysh River, near the confluence with the Ob River in the middle taiga area of western Siberia, about 20 km from Khanty-Mansiysk (60°54′ N, 68°42′ E). This region is located in the Boreal climate zone, which corresponds to the Sub-Arctic climate zone of western Europe (Fig. 1). The mean annual temperature is −1.3°C, the coldest month being January with a mean temperature of −18.9°C; the warmest month is July, with a mean temperature of 17.1°C. The mean annual precipitation is 553 mm (Kremenetski et al., 2003). In 2009, the Mukhrino Field Station was built at the margin of a giant mire complex. It is managed by the UNESCO Chair of Environmental Dynamics and Climate Change at Yugra State University, Khanty-Mansiysk, Russia (Elger et al., 2012). The Mukhrino mire complex is typical for the West Siberian middle taiga. It is a complex of oligotrophic-raised bogs (*Pinus sylvestris* and *P. sibirica*, *Eriophorum vaginatum*, *Ledum palustre*, *Chamaedaphne calyculata*, *Betula nana*, and *Sphagnum fuscum*) patterned with ridge-hollows (*Carex limosa*, *Scheuchzeria palustris*, *Sphagnum balticum*, *S. jensenii*, and *S. papillosum*) and oligo-mesotrophic fens (*Carex rostrata*, *Menyanthes trifoliata*, *E. russeolum*, *S. fallax*, *S. jensenii*, and *S. majus*) (Filippov and Lapshina, 2008). This area is characterized by the absence of permafrost (Bleuten and Filippov, 2008). The Mukhrino peatland has a peat thickness between 3 m and 4.5 m. Its hydrology is dependent on micro-topography and changes seasonally. During the summer, groundwater in poor fens and hollows is between 5 cm and 20 cm below the moss surface, while in raised bog areas with *Sphagnum* hummocks, the water table is 40–80 cm below the surface (Bleuten and Filippov, 2008).

Materials and methods

Field sampling

In summer 2012, a 1-m-long peat core was sampled with a long serrated knife and sliced in the field into 1-cm samples. Each slice was

Figure 1. Map of Eurasia showing the location of Mukhrino mire and indicating the range of boreal forests.

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