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Drought as a stress driver of ecological changes in peatland - A palaeoecological study of peatland development between 3500 BCE and 200 BCE in central Poland

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ABSTRACT

We reconstructed 3300 years (3500 BCE and 200 BCE) of the development history of the Rąbień peatland located in central Poland, using pollen, macrofossil, testate amoebae, Cladocera, Chironomidae and geochemistry. Central Europe, particularly Poland, is characterised by a transitional climate that is influenced by continental and Atlantic air masses, which makes this region very sensitive to climate change. Our results demonstrate the high potential of the Rąbień peat record to reconstruct palaeohydrological dynamics. The studied time interval is characterised by two pronounced dry periods: from ~2500 to ~1700 BCE and from ~700 to ~500 BCE, and two significant increases in the water table: from ~1000 to ~800 BCE and from ~500 to ~250 BCE. The timing of the wet shift at 600 BCE corresponds to wet periods at different sites in Central and Eastern Europe. Our investigation reveals a more complicated and complex than previously assumed set of climatic relationships in Europe between 3500 BCE and 200 BCE, which might be linked through complex teleconnections of atmospheric circulation patterns. Only reconstructions that are based on an understanding of current observations from peatlands and lake ecosystems may lead to a better interpretation of past climate changes.

1. Introduction

Changes in hydrology are the main drivers of the processes that occur in peatland ecosystems, e.g. changes in species composition of biotic assemblages, and the accumulation and decomposition of organic matter (Charman, 2002; Rydin and Jeglum, 2006). Hydrological changes in mires can also be caused by various non-climatic factors, such as autogenic processes (Birks and Birks, 2004). Nevertheless, climate remains the dominant factor, with precipitation and temperature affecting the local humidity and hydrological conditions. This is demonstrated by modern observations of relationships between weather conditions and water table changes in peatlands (Marcisz et al., 2014; Słowińska et al., 2010). Peatland ecosystems are sensitive to human impacts, e.g. deforestation (Ireland and Booth, 2012; Lamentowicz et al., 2007; Warner et al., 1989), drainage (De Vleeschouwer et al., 2009; Holden et al., 2011), and pollution (Fialkiewicz-Koziel et al., 2015). Bio-indicative properties of different groups of organisms (e.g. Cladocera, Chironomidae, testate amoebae or diatoms) and plants (pollen and plant macro-remains) enable us to reconstruct changes that have occurred in the past, based on analyses of biogenic sediments (Chambers et al., 2012; Lamentowicz et al., 2010; Marcisz et al., 2015; Słowiński et al.,

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2015). A growing number of studies have utilised a multi-proxy approach for peat profiles, providing the possibility to reconstruct, e.g., the hydro-climate or land cover over large spatial scales. Only then can we perform a reconstruction of local (Lamentowicz et al., 2015b), supra-regional (Swindles et al., 2013), or global changes (Charman et al., 2013). Successful investigations of micro-tephra from volcanic eruptions in Central Europe have been reported, with which we can actually synchronise archives (lake sediments and peat), and thus analyse leads and lags in the responses of ecosystems to environmental changes (Housley et al., 2013; Lane et al., 2013; Ott et al., 2016; Tylmann et al., 2016; Wulf et al., 2016; Wulf et al., 2013).

For the Holocene, several climate fluctuations have been reported. The most prominent being 9.3 and 8.2 ka events (Bond, 1997). These events were possibly caused by changes in the air circulation across the north Atlantic and have been reported at multiple positions worldwide (Bjorck et al., 1997; Fisher et al., 2002; Hoek and Bos, 2007; Yu and Wright, 2001), recently also in central Poland (Kittel et al., 2016). A completely different mechanism that affected climate changes during the 4.2 and 2.8 kyr BP episodes has been described by a complex set of interactions within the global ocean-atmosphere circulation system and solar activity (Arz et al., 2006; Martin-Puertas et al., 2012; Mayewski et al., 2004; Neugebauer et al., 2015). There are still important questions that need to be answered: 1) which well-known events that are listed worldwide (e.g. 4.2 BP or 2.8 BP) were registered in Central Europe?; 2) How are they marked in palaeoecological archives?; and 3) what was the feedback of these global climate changes on ecosystems in this part of Europe?

Climate conditions have special significance in Central Europe, particularly in Poland, where continental and Atlantic air masses collide (Woś, 1999). Areas located in such transitional zones – at climatic borders – seem to be very sensitive indicators of climatic signals. Therefore, the Rąbień mire carries high palaeoecological potential to supplement our current understanding of changes during the post-glacial history of Central Europe. By comparing instrumental and proxy data, studies focusing on the reconstruction of climate changes in Central Europe are significant, because of the representativeness of the results in broader European terms (Luterbacher et al., 2004; Luterbacher et al., 2010; Pauling et al., 2006). During the last decade, new hydro-climate reconstruction data with multi-proxy high resolution analyses have been recorded from the raised bogs in the southern Baltic, and they reveal interesting interactions between climate and human activities during the last 1000 to 2000 years (Gałka et al., 2013; Gałka et al., 2014; Lamentowicz et al., 2008b; Lamentowicz et al., 2015b). High-resolution multi-proxy palaeoecological investigations from peat archives with special attention being paid to relationships with archaeological knowledge are still not common in Central Europe.

The Rąbień peatland is the first peatland in central Poland to be analysed with six biotic proxies (plant macrofossils, pollen, Cladocera, Chironomids, testate amoebae and geochemistry), which were compared with archaeological sources. We focused on 3300 years of the developmental history of Rąbień mire to track the hydroclimatic changes and increasing human disturbance that we expected to have been recorded in the peatland. We assumed that the most important palaeohydrological changes in the studied peatland were initiated along with general climatic changes, and their consequences on biotic and abiotic realms will be visible in the entire mire catchment. In this study we: i) reconstruct palaeohydrological changes between 3500 BCE and 200 BCE from the Rąbień *Sphagnum*-peatland using a multi-proxy analysis that is based on macrofossils, testate amoebae, Cladocera, Chironomidae, geochemistry and ash content data, which reflect local environmental changes; ii) assess the response of the lake and peatland ecosystem to climatic fluctuations; iii) investigate how the hydrological changes were connected with human activities; and iv) pay special attention to a comparison of our results with other records from Central Europe and synchronise records of environmental changes.

2. Materials and methods

2.1. Study area

Rąbień mire (φ51°48′20″N; λ19°18′05″E; 189 m a.s.l.) is located in central Poland (Fig. 1) in the Łask Plateau mesoregion (Kondracki, 2001), 130 km from the Warsaw. The mire catchment area is 68 ha, but the mire covers 42 ha (Forysiak, 2012). Rąbień mire is situated in formerly glaciated landscapes on a flat moraine plateau, a part of the Lutomiersk Hills (Dylik, 1948). The relief that surrounds the mire is polygenetic (Dylikowa, 1970). Dunes in the close vicinity of the site are of parabolic type, formed during the Older Dryas (Forysiak, 2012). The origin of the mire depression has long been discussed (Dylik, 1970; Jahn, 1970; Klatkowa, 1997), although its formation was probably connected to the development of a thermokarst basin (Forysiak, 2012). Mire developed after terrestrialization of a lake (Fig. 1). A geological survey by Forysiak (2012) revealed that the maximum thickness of the biogenic deposits is 6.2 m (Fig. 1). Rąbień mire has previously been investigated with a focus on its palaeobotanical changes, geology and phytosociology (Balwierz, 2005; Kloss and Żurek, 2005; Kucharski and Kloss, 2005). This mire is protected as part of a botanical nature reserve (Żurek, 2006). Based on its vegetation, the contemporary Rąbień mire is classified as a bog (Kucharski et al., 2004). The present-day vegetation of the mire is covered by a mosaic of patches of *Eriophorum angustifolium-Sphagnum fallax* and *Eriophorum vaginatum-Sphagnum fallax* communities (Kucharski et al., 2004). During the 19th and 20th centuries, the southern and eastern parts of the mire were drained. Afterwards, the mire was covered with a mixed coniferous forest *Querco roboris-Pinetum*. Only the central part of mire still has patches of semi-natural oligotrophic vegetation (Kucharski et al., 2004). The average annual precipitation on the Łask Plateau (data for the period from 1954 to 1968) is 563.5 mm and the average annual temperature is 7.3 °C (data from Łódź-Lublinek station – Roczniki Hydrograficzne & Meteorologiczne, 1954–1968).

2.2. Prehistoric human activity in the mire area

Three archaeological sites have been recorded on the dune in the close vicinity of the mire. The distance between the sites and the analysed peat core R-II is approximately 550–800 m. Archaeological relicts of Late Palaeolithic and Mesolithic campsites have been discovered at the sites (Niesiołowska-Śreniowska, 2011; Niesiołowska-Śreniowska and Płaza, 2011). These relicts are older than 3500 BCE. The only evidence of the activity of Neolithic communities at the site is C^{14} data of charcoal from hearths, i.e. 3800–3600 BCE (Niesiołowska-Śreniowska and Płaza, 2011). Some geoarchaeological records of human activity are represented by sheets of aeolian sands and they have been radiocarbon-dated to the Meso- or Neo-Holocene. The second aeolian series has been connected with human impacts during the Late Mesolithic or the Late Neolithic and the Bronze Age (between 4600–4340 BCE and 1600–1210 BCE). The third aeolian series deposition is associated with the Early Iron Age (770–430 BCE), and the last aeolian activity is more recent than 530–640 BCE (Marosik, 2011). These results have not been confirmed by archaeological records in the close vicinity of the mire. The Polish Archaeological Record (Barford et al., 2000) lists another archaeological site at a distance of ca 1.5 km from the mire (Fig. 1). Twenty-eight archaeological sites totally with 43 archaeological chronological horizons have been evidenced at a distance of no >5 km from the mire. In this collection, 34 sites have been dated to periods later than 2530 BCE (4000 yr BP), with 11 in this group dating back to prehistoric times. Based on archaeological evidence, the mire was seemingly not under strong human influence from 3500 to 200 BCE, i.e. during the Late Neolithic, the Bronze Age, and the Early Iron Age. In the Polish lowlands, especially in central Poland, a concentration of archaeological sites is observed in river valleys (Kittel, 2012). The mire is situated in a watershed area, which is most likely the reason for the