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Rich fen development in CE Europe, resilience to climate change and human impact over the last ca. 3500 years

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ABSTRACT

Here, for the first time in SE Poland, we document the long-term development of a rich fen and assess its sensitivity to climate change and human impacts over the last ca. 3500 years. Our results are based on a high-resolution, continuous plant macrofossil remains, mollusc and pollen record, complemented by geochemical, mineral magnetic and physical characterisation, and radiocarbon dating from Bagno Serebryskie rich fen located in SE Poland. Based on the palaeoecological data we distinguished five stages of wet habitat conditions: 5000–3300, 2800–2150, 1600–1100, 750–230, 150–10 cal yr BP and five dry periods at ca. 3300–2800, 2150–1600, 1100–750, 230–150, 10 to −64 cal yr BP. The pollen and geochemistry records, particularly Pb, show that the first human activity in the study area occurred ca. 3200 cal yr BP and increased markedly from 500 cal yr BP affecting local plant development including the population size of *Cladium mariscus*. Our study has shown that despite human impact (drainage, fire), Bagno Serebryskie peatland has hosted rare, presently protected species, such as *Cladium mariscus* for hundreds of years. We conclude that, in common with ombrotrophic bogs, rich fen ecosystems can provide a reliable source of palaeoclimatic and palaeohydrological data. Our study also shows that a large peatland (376 ha) can be as sensitive a palaeohydrological archive as smaller mires.

1. Introduction

Rich fens are among one of the most important wetland ecosystems; occupied by endangered, vulnerable and protected plant communities (Grootjans et al., 2006). The development of rich fens depends primarily on the supply of minerotrophic water carrying nutrients from the catchment soils and rocks. Rich fens are not only fed by groundwater but also by rainfall. In contrast to poor fens and bogs, waterlogged rich fens are species-rich, with vegetation dominated by Cyperaceae (e.g. *Carex*, *Cladium*, *Schoenus*) and bryophytes (e.g. *Campylium*, *Scorpidium*, *Calliergonella*) (Slack et al., 1980; Hájek et al., 2006). Studies focusing on various aspects of recent rich fens, including their ecology, the distribution of plants and restoration have been carried out (Salmina, 2004; Mälson and Rydin, 2007; Ilomets et al., 2010; Kotowski et al., 2013; van Diggelen et al., 2015).

Effective management strategies to protect or restore rich fens require adequate knowledge of the development of these threatened wetland ecosystems (Seddon et al., 2014; Clarke and Lynch, 2016). The history of fens has been described in various studies (e.g. Swinehart and Parker, 2000; Bauer et al., 2003; Yu, 2006; Bauer and Vitt, 2011; Hájková et al., 2013; Lamentowicz et al., 2013; Gałka et al., 2016a), however, knowledge of the drivers of the rich fen development is lacking. Multi-proxy palaeoecological studies aiming to reconstruct the internal and external drivers of the development of rich fens in Central Europe have only been undertaken at the Stążki rich fen site in the lowlands of northern Poland (Lamentowicz et al., 2013), in Male Bielice, a mountainous area in the Western Carpathians, Slovakia (Hájková et al., 2013) and at Apšuciems Mire, an extremely rich fen in a dune area on the southeastern Baltic coast of Latvia (Gałka et al., 2016a). These studies have shown that changes in plant succession in rich fens ecosystems are complex and can be linked to climatic changes, human impacts and internal aspects of these ecosystems.

Our palaeoecological study focuses on the development of Bagno Serebryskie (BS) rich fen (ca. 376 ha), one of the largest peatlands in Central Europe, developed in an outflow depression in a karst area. In

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this study we aim to reconstruct the response of this rich fen to climate change, human impacts and fire during the late Holocene. To accomplish this aim a high resolution (1–3 cm), multi-aspect palaeoecological analysis (plant macrofossils, pollen, molluscs, geochemistry, mineral magnetic and physical property characterisation, macrocharcoal and ^{14}C dating) of two peat profiles from BS was undertaken. Furthermore, the site has one of the largest populations of *Cladium mariscus* L. (Pohl) in Central East Europe (CE Europe); a rare, endangered, and vulnerable plant in rich fen ecosystems (Gałka and Tobolski, 2012; Hájková et al., 2013). The study area is located at the current eastern range limit of *C. mariscus* in Europe, which makes it particularly sensitive to changes in climatic conditions, and therefore a potentially promising bioindicator. The species has previously been observed to be a good indicator of warm climate phases (cf. Berglund, 1968; Walter and Straka, 1970). The main objectives of this study are: i) to determine the influence of allogenic (climate change and human impact) and autogenic drivers of rich fen development over the late Holocene; ii) to identify the factors responsible for the spread of *C. mariscus*, presently one of the common plants on this peatland; iii) to define the variability in local vegetation development by using two parallel peat cores as replicates. This approach is rarely employed in palaeoecological studies, and mainly in ombrotrophic peatlands (Lamentowicz et al., 2011; Gálová et al., 2016; Gałka et al., 2016a), but it is crucial for the validation of paleoenvironmental interpretations, especially for testing the impact of recent climate change on local vegetation in different parts of peatlands (Charman et al., 1999). We hypothesise that i) the studied rich fen responded sensitively to both late Holocene climatic fluctuations and the intensification of human activity, including deforestation, fire and pollution, and ii) past climate variability of the late Holocene (warm and cold phases) significantly affected the range distribution and abundance of the population of *C. mariscus* at the study site. Our palaeoecological approach will contribute to a better ecological and biogeographic understanding of rich fens and will improve the assessment of potentially sensitive areas for *C. mariscus* to future environmental change.

In our study, we use the term rich fen in accordance with the European Nature Information System habitat classification (EUNIS, http://www.eunis.eea.europa.eu/); rich fens are assigned to type D4.1: rich fens, including eutrophic tall-herb fens and calcareous flushes and soaks (Davies et al., 2004).

2. Study site

Bagno Serebryskie peatland (ca. 376 ha), protected as a nature reserve since 1991, is located in southeastern Poland in the northern part of the Chełm Hills subregion of the Lublin Upland (170–220 m a.s.l., Fig. 1). The peatland developed in a closed sinkhole; a common geomorphological landform in this karst area (Wojtanowicz, 1994; Dobrowolski et al., 2015). During the Late Glacial and early Holocene many of these sinkholes functioned as shallow lakes as evidenced by the presence of calcareous gyttja below the peat deposits (Alexandrowicz et al., 1994; Buczek, 2005; Dobrowolski et al., 2015). The Chełm Hills subregion was glaciated at least twice (Elsterian and Saalian), but was not directly affected by the last glaciation (Weichselian). Quaternary deposits accumulated directly on Upper Cretaceous carbonate rocks i.e. limestones, marls and chalk (Krassowska and Niemczycka, 1984); including sands, gravels and diamictons of Saalian glaciogenic origin, Weichselian fluvial and limnic periglacial sands and silts, and Holocene peat, gyttja and muds.

The climate of the area is continental, with a mean annual temperature of 8 °C, a mean July temperature of 17.5 °C and a mean January temperature of −3.5 °C. Annual precipitation averages 550 mm (Lorenc, 2005).

In the northern, wetter part of the peatland, where the sampled sites are located, *Cladium mariscus* was a dominant plant species at the time of field sampling. The vegetation also included *Phragmites australis*, *Mentha aquatica*, *Lythrum salicaria*, *Utricularia intermedia* and *Carex elata*. In the marginal, drier parts of the peatland, adjacent to the *C. mariscus* community, *Carex hostiana*, *Carex buxbaumii*, *Salix rosmarinifolia*, *Schoenus ferrugineus*, *Epipactis palustris*, and *Sanguisorba officinalis* were found. Among the mosses present *Campylium stellatum*, *Scorpidium cossonii*, and *Bryum pseudotriquetrum* were noted.

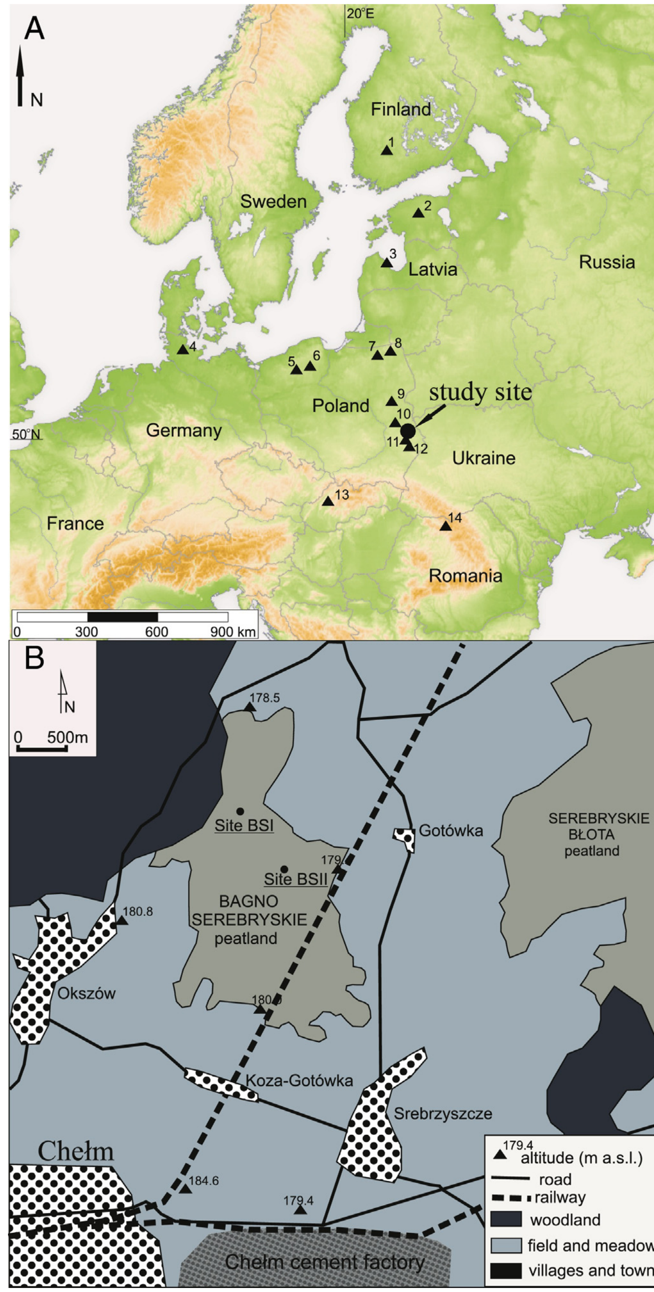

Fig. 1. A. Site location in Central Europe (source: http://pl.wikipedia.org/w/index.php?title=Plik:Europe_topography_map.png&filetimestamp=20080612084157, Author: San Jose; modified) and the location of sites (black triangles) cited in the text: 1) Kontolanrahka bog (Väliranta et al., 2007), 2) Männikjärve bog, Estonia (Sillasoo et al., 2007); 3) Apšuciems Mire (Gałka et al., 2016a), 4) Dosenmoor bog (Barber et al., 2004), 5) Bagno Kusowo bog (Lamentowicz et al., 2015a), 6) Stążki fen (Lamentowicz et al., 2011), 7) Gązwa bog (Gałka et al., 2015), 8) Lake Purwin (Gałka and Apolinarska, 2014), 9) Radzików spring-fed fen (Dobrowolski et al., 2012), 10) Lake Słone (Kulesza et al., 2012), 11) Krzywce spring-fed fen (Dobrowolski et al., 1999), 12) Komarów spring-fed fen (Dobrowolski et al., 2016), 13) Male Bielice spring-fed fen (Hájková et al., 2013), 14) Taul Muced bog (Feurdean et al., 2015). B. location of drilling sites within the Bagno Serebryjskie peatland (black dots).

Agriculture dominates in the vicinity of the peatland. To the west and northwest the peatland is bordered by coniferous and broad-leaved