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Original Articles

Cascading effects between climate, vegetation, and macroinvertebrate fauna in 14,000-year palaeoecological investigations of a shallow lake in eastern Poland

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ABSTRACT

Late glacial and Holocene environmental history of Lake Łukie and its catchment is reconstructed from the lake sediments. This shallow lake is situated in the marshy Polesie region in eastern Poland. Sediments began to accumulate in the lake in the Older Dryas. On the basis of macrofossils, pollen, and Oribatida remains, and with the use of Kohonen's artificial neural network (self-organising map, SOM), six stages (corresponding to subclusters X_1, X_2, X_3 in cluster X, and Y_1, Y_2, Y_3 in cluster Y) of the lake history were distinguished, and indicator taxa of each stage were identified from the indicator value (IndVal) index. During the transition period corresponding to the border between X and Y, the ecosystem transformed in the broad sense from the protocratic to mesocratic phase in a 5-point scale transformation of the landscape in the glacial–interglacial cycle. All the steps involved in post-glacial history succession during interglacial cycles include changes in climate, soil, and biotic interactions. Indicator taxa for the subsequent SOM subclusters X_1, X_2, and X_3 are associated with the first phase of the protocratic glacial–interglacial cycle. The transformation that occurs on the level of cluster Y (subcluster Y_1) is the mesocratic phase (ca. 9000–5000 ^{14}C age BP), which is characterised by high temperatures and development of closed forest (climax forest). Subcluster Y_2 corresponds to the transformation of forest cover during the oligocratic phase (ca. 5000–3000 ^{14}C age BP), which is associated with decreasing forest share and deteriorating soils. Finally, subcluster Y_3 can be associated with the telocratic phase, characterised by the influence of a more oceanic climate (from ca. 2500 ^{14}C age BP) with declining temperatures, higher humidity, and milder seasonal contrasts, which contributed to the development of more open vegetation and infertile soils. This stage also corresponds to an increased human activity and landscape transformation, such as from forests to cornfields and from wetlands to meadows. Interestingly, the currently strictly protected brittle naiad (*Najas minor*) was present in the lake during the Atlantic, Subboreal, and Subatlantic periods; however, this species is not listed as being part of the present vegetation and may have become extinct relatively recently.

1. Introduction

"Palaeoecology is the ecology of the past" (Birks and Birks, 1980), and it focuses on understanding the relationships between organisms and environment. In order to reconstruct the past environment, we need to analyse bioindicators (Birks and Birks, 1980). Macrofossil analysis is one of the primary methods that is used for palaeoecological reconstruction. The analysis is based on the bioindicator value of the fossil remains of stenotopic plants and animals that enable the reconstruction of multiple environmental variables. The possibilities for

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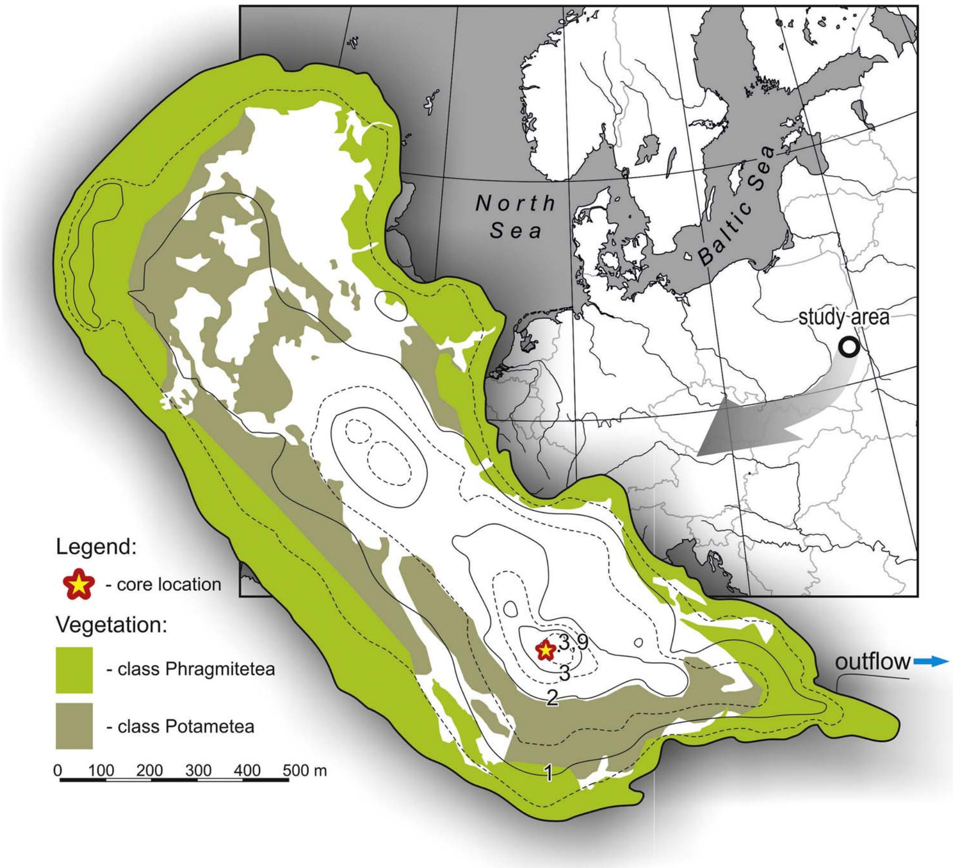

Fig. 1. Bathymetry and vegetation map of study site – Lake Łukie (showing the location of the site where core LŁ was taken).

such an analysis are broad and comprise the reconstruction of local changes occurring in peatlands or lakes that often reflect global changes, such as changes in the trophic state index of ecosystems (Hannon and Gaillard, 1997; Holmes et al., 2010; Lamentowicz et al., 2015; Marcisz et al., 2015), air temperature (Birks and Birks, 2008; Peteet, 2000; Zawiska et al., 2015, 2017), lake water level (Almquist-Jacobson, 1995; Dietze et al., 2016; Harrison and Digerfeldt, 1993; Latałowa and Borówka, 2006; Słowiński, 2010; Słowiński et al., 2015), climate and solar forcing (Barber and Langdon, 2007; Blaauw et al., 2004; Charman et al., 1999; Słowiński et al., 2016), human impact referring to land use in the catchment and modifications of the hydrological regime (Marcisz et al., 2016; Ramdani et al., 2001; Rasmussen and Anderson, 2005), and environmental pollution (Davidson et al., 2005; Fialkiewicz-Koziel et al., 2016; Sand-Jensen et al., 2008). Moreover, macrofossil analysis is also used in archaeological and interdisciplinary research (Risberg et al., 2002; Słowiński et al., 2017; Święta-Musznicka et al., 2013; van Geel et al., 2008).

Research on oribatid mites is a relatively new area of palaeolimnology. Recently, there has been a substantial interest in palaeoecological reconstructions based on fossilised Oribatida (Bennike et al., 2007; de la Riva-Caballero et al., 2010; Heggen et al., 2010; Hodgson and Convey, 2005; Larsen et al., 2006; Solhøy and Solhøy, 2000). Fossil oribatid mites in lake and bog sediments complement paleoenvironmental reconstructions (Solhøy, 2001). Oribatid mites are small chelicerate arthropods that constitute a species-rich order in the subclass Acari. Globally, the order includes ~11,000 species (Walter and Proctor, 1999). Oribatids also show high local diversity, with up to 150 species coexisting in a small area in the soil of temperate forests (Norton et al., 1993). The remains of oribatid mites outnumber those of insects (apart from chironomids) in nearly all archaeological and palaeoecological samples (Schelvis, 1990). With the exception of some primitive superfamilies, adult oribatids have a hard, compact, and resistant chitinous exoskeleton, which can be preserved in most terrestrial and limnic sediments (Solhøy and Solhøy, 2000). These traits mean that mites are found demonstrably close to their real 'home territory' (Erickson and Platt, 2007). Moreover, these mites have short generation times; therefore, they can quickly respond to rapid and/or temporary environmental changes (Baker, 2009). Several species have rather narrow niches because they are associated with certain groups of macrophytes and bryophytes, which provide microhabitats for these species (Schatz et al., 2002). Heggen et al. (2010) emphasised that there may be considerable morphological differentiation between species that are related to the wide range of microhabitats. All of these characteristics make oribatid mites good indicators of the local environmental history (Drouk, 1997; Erickson, 1988; Solhøy and Solhøy, 2000; Solhøy, 2001). Accurate interpretation of the records of samples largely relies on the available data from many taxonomic and ecological studies of oribatids in modern soils (Baker, 2009). On the one hand, our understanding of the composition of modern communities and the niche requirements of present-day species in most parts of the world is limited (Solhøy and Solhøy, 2000). On the other hand, paleontological evidence suggests that mite habits have not changed substantially over time (Schelvis, 1992). The present work pioneers the application of oribatid mites to palaeoecological analysis in Poland.

This study focuses on reconstructing environmental changes in the late glacial and Holocene development of Lake Łukie in eastern Poland. Special attention is given to (1) changes in local and regional vegetation (based on macrofossils and pollen, respectively), (2) changes in lithology, and (3) the use of oribatid mites (in combination with plant remains) for reconstructing terrestrial and aquatic community development in this shallow lake.

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