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# Response of the aquatic plants and mollusc communities in Lake Kojle (central Europe) to climatic changes between 250 BCE and 1550 CE

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ABSTRACT

Sediments of Lake Kojle, located in the transition zone between the nemoral and boreal biogeographic zones in NE Poland, were analysed to verify the response of the aquatic ecosystem to major environmental changes. High-resolution plant macrofossil, mollusc and pollen data were derived from two replicate parallel cores and revealed several shifts in the biota composition within the littoral zone between 250 BCE and 1550 CE. The reaction of the aquatic ecosystem to temperature changes was found to be minor, which is ascribed to the mitigating influence of water and the wide ecological tolerance of most of the taxa. *Najas marina*, considered as an indicator of warmer conditions, was the only species that clearly reacted to the long-term climate shifts. We consider lake level changes that resulted from fluctuations in climate humidity and the filling of the lake with sediments as the most important factors that control the presence of macrophytes species from the genera *Nymphaea*, *Nuphar*, *Typha*, and *Chara*. Mollusc diversity and abundance increased with the increase in the diversity and biomass of submerged vegetation. However, reduced dissolved oxygen within the water column under the floating leaves of *Nymphaea alba* and *Nuphar* sp. resulted in the retreat of *Planorbis carinatus*, a gastropod species sensitive to oxygen shortages. Major shifts in the developments of fauna and flora were parallel in the two studied cores, but some spatial variability was observed. This might be due to the spatial variability of the macrophyte and mollusc communities within Lake Kojle.

## 1. Introduction

Littoral zones of lakes are among the ecosystems that are reacting rapidly to climate change due to their restricted areas and small water volumes. The direct responses to changes in air temperature and precipitation include changes in water temperature and lake depth, whereas the indirect responses include shifts in the lake mixing regime, water chemistry or nutrient cycling and availability (Clarke, 2009; Vincent, 2009).

The specific composition of plants and animals within littoral zones of lakes are diverse. They are determined by a range of environmental conditions including temperature, water depth, water chemistry, pH, water turbidity and duration of the ice cover, all of which are directly or indirectly controlled by the climate (Søndergaard et al., 2010). Therefore, climate change can potentially lead to a considerable reorganization of the lake ecosystem by extinction or alteration of aquatic organisms. The eventual response to climate change is species-specific and depends on the ability of the species to adapt to the altered environmental conditions.

In recent years, the prediction of future conditions of lacustrine ecosystems in a continuously changing climate has become an urgent matter (Jeppesen et al., 2014). The studies that have described the recent responses of freshwater fauna and flora to climate change include in situ observations in lakes (Pełechata et al., 2015), experimental studies using microcosms (McKee et al., 2002) and mesocosms (Patrick et al., 2012) but also models predicting the occurrence of aquatic species under an applied climate scenario (Auderset Joye and Rey-Boissezon, 2015). However, all the above approaches are burdened with limitations, including short observation periods, inability to imitate natural ecosystems within the microcosms or mesocosms (Mckee et al., 2002; Patrick et al., 2012) and limitations of the species distribution models (Auderset Joye and Rey-Boissezon, 2015). These limitations have been complemented with studies of lacustrine sediment sequences where long-term ecosystem responses to natural

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climate variations, changes in lake catchments and internal processes within the lake can be explored (Birks et al., 2000; Gałka et al., 2014). Palaeoenvironmental reconstructions are based on a variety of biotic and abiotic proxies that are preserved in lacustrine sediments (Birks and Birks, 2006). The abiotic proxies include sediment geochemistry and stable isotope composition of the selected material, e.g., organic matter and carbonates (Leng et al., 2005; Reuss et al., 2010). Biotic indicators include plants: macrophytes and algae (Haas, 1996; Bradshaw et al., 2005; Väliranta, 2006), and animals: molluscs, Cladocera, and Chironomidae (Alexandrowicz, 2007; Pawłowski et al., 2015). In the studies of lake sediments, most attention has been paid to species that find appropriate habitat under restricted environmental conditions (Hannon and Gaillard, 1997). Detailed data on water temperature, water depth, pH and lake trophy can be inferred from these indicator species. However, many aquatic organisms have wide ecological tolerances and can easily adapt to changes in the ecosystem (Lacoul and Freedman, 2006; Søndergaard et al., 2010). Responses of biota to climatic changes are strongest under border conditions (Reuss et al., 2010) and in locations characterized by transitional conditions, e.g., variable influences from contrasting air masses (Gałka et al., 2014). In areas where changes in temperature and humidity are well recognized, palaeoenvironmental data allow to follow the reactions of ecosystems and particular species to climatic changes.

The present study focuses on the responses of aquatic plants and molluscs from the littoral zone in Lake Kojle, north-eastern Poland (Fig. 1) to the well-established (Büntgen et al., 2011; PAGES 2k Consortium, 2013; Luterbacher et al., 2016; Gałka et al., 2017) climatic changes between 250 BCE (before common era) and 1550 CE (common era). The study area in northeast Poland was selected due to its specific location in the transitional zone between oceanic and continental influences and is the transition zone between the nemoral and boreal biogeographic zones (Gałka et al., 2014).

According to our hypothesis, the aquatic plant and mollusc communities responded to climatic fluctuations between 200 BCE and 1550 CE. Temperature changes can be tracked by the records of temperature-sensitive taxa, whereas shifts in humidity are reflected by the changes in aquatic vegetation associated with particular water depths. To verify this hypothesis, we aimed to identify the species of plants and molluscs that responded sensitively to warm periods, such as the Late Iron Age (Late IA), Roman Period (RP), and Medieval Climate Anomaly (MCA), which themselves were separated by cold intervals, including the Migration Period (MP) and the beginning of the Little Ice Age (LIA). In our second aim, we evaluated the sensitivity of the fauna and flora from Lake Kojle to the local (northeast Poland) and regional (central Europe) changes in climate humidity. We also aimed to determine the impact of macrophytes on the diversity of malacofauna and to define the variabilities in local vegetation and mollusc development by using two parallel cores as replicates.

## 2. Materials and methods

### 2.1. Description of the study area

Lake Kojle is located in northeast Poland (Fig. 1) in the Suwałki Landscape Park. The morphology of the study area was largely influenced by the Scandinavian ice sheet during the Weichselian glaciation (Marks, 2012), and the limit of the Pomeranian Phase ice sheet was approximately 7 km south of Lake Kojle, as estimated at ca. 16–17 ka cal yr BP (Marks, 2012). The numerous lakes and peatlands in the area are located among morainic and kame hills with elevations up to 270 m a.s.l., and the differences in relative heights frequently exceed 50 m.

Lake Kojle has a maximum depth of 33 m and covers an area of 17.1 ha. The water level in the lake is approximately 148.3 m a.s.l. In the past, Lake Kojle was connected to the neighbouring lakes Perty and Purwin, evidenced by the continuity of the biogenic deposits between the lakes (Gałka and Apolinarska, 2014). The oldest lacustrine deposits in the area from Lake Kojle date back to ca. 14,000 cal yr BP (Gałka et al., 2015). At present, *Nymphaea alba* and *Chara* spp. occur in the lake in the areas surrounding the coring sites. *Cladium mariscus* and *Phragmites australis* grow in the rush zone, which is bordered by a belt of *Carex elata* and *Thelypteris palustris* and then by a sparse *Alnus glutinosa* swamp where *Thelypteris palustris* grows abundantly. The other common plant species in this swamp belt include *Phragmites australis, Carex paniculata,* and *Frangula alnus*. The moss layer is weakly developed and consists of mainly *Climacium dendroides, Brachythecium* sp. and *Plagiomnium ellipticum*.

The study area is located within the temperate climate zone, in the transitional zone between oceanic and continental influences, with continental air masses prevailing. The mean annual air temperature is 6.1 °C, and the monthly average ranges between −5 °C in January and 17 °C in July (Lorenc, 2005). The total mean annual precipitation is 650 mm, with the maximum precipitation occurring in July and the minimum precipitation occurring in February.

### 2.2. Sediment sampling

The selection of the coring sites was preceded by a detailed recognition of the extent of sediments with well-preserved and abundant plant macrofossils and mollusc shells deposited in the littoral zone of the formerly more extensive Lake Kojle (Gałka, 2014). A previous study that described the Holocene development of Lakes Kojle and Perty showed no hiatuses in the record. Two 300 cm long sediment sequences, Kojle I (Koj I) and Kojle II (Koj II), were drilled on the surface of the peatland adjacent to the southern shore of Lake Kojle, 2 m from open water (Fig. 1) using a Russian peat corer (Instorf type) that was 7 cm in diameter and 100 cm in length. The distance between the two cores was approximately 20 m. The sediment segments were wrapped tightly in plastic foil and transported to a cold room with a constant temperature of 4 °C at the Department of Biogeography and Palaeoecology in Poznań.

### 2.3. Identification of fossil records

To ensure the precision and quality of the data and ability to distinguish even small-scale climatic fluctuations and shifts in the abundances of fauna and flora, a high sampling resolution of the two sediment sequences was employed. Plants and mollusc macrofossils where determined in both cores, whereas pollen and algae were determined only in core Koj II.

The deposits for plant macrofossil analysis were sampled at 1 cm resolution. In total, 597 samples, each approximately 15–16 $cm^3$ in volume, were collected. The samples were rinsed in warm water on 0.2 mm mesh sieves. Plant macrofossils were identified with the use of a Nikon SMZ800 stereoscopic microscope at the magnification of 10–200 ×. Individual plant macrofossils were identified with the help of the appropriate keys Velichkevich and Zastawniak (2006, 2008). The plant macrofossils have been summarized in the diagrams in absolute numbers. The plant nomenclature follows that of Mirek et al. (2002). Stratigraphic changes in plant macrofossil assemblages allowed different plant macrofossil phases to be distinguished (e.g., Koj I-pm-1). The ecological requirements of several plant species (Hannon and Gaillard, 1997; Zarzycki et al., 2002) were used to distinguish the water level changes in the lake. After the plant macrofossils were extracted, the sediment samples from the Koj I and Koj II cores were examined for mollusc shells. The shells were hand-picked and identified under a low-power binocular microscope (Zeiss Stemi 2000-C) using the reference collection from the Institute of Geology in Poznań and keys and atlases (Ložek, 1964; Piechocki, 1979; Welter-Schultes, 2012). The absolute numbers of mollusc shells were used for diagrams. The mollusc nomenclature follows that of Welter-Schultes (2012). Stratigraphic changes in mollusc assemblages allowed different mollusc phases to be