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Reaction of the lake environment to the Holocene warming depending on the distance to the maximum extent of the Vistulian ice sheet

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ABSTRACT

This study presents 1) the results of a stable isotope and subfossil Cladocera analyses of lacustrine sediments from Maliszewskie Lake (E Poland) and next 2) different reaction of the lake environments depending on the lake's localization. Maliszewskie Lake is located in North Podlasie Lowland ca. 30 km to the south of the Vistulian ice sheet limit. The approximately 4.80-m-thick sediments (Maliszewo I profile) are mainly comprised of calcareous gyttja covered by peat and organic detritus gyttja. Pollen analysis documents that the sediments accumulated from the Late Glacial (Allerød period) to recent times. Based on the results of stable isotope and subfossil Cladocera analyses of sediments, the lake environmental changes were reconstructed. A positive trend in $\delta^{18}O$ and $\delta^{13}C$ values documents a gradual climatic warming. The fluctuations of the oxygen isotopic values suggest the multiple oscillation of water level due to a change in the evaporation/precipitation ratio. The subfossil cladoceran fauna in the Maliszewo I profile is represented by 21 species belonging to five families. Three zones of Cladocera development were distinguished. The Cladocera species indicate the initial oligotrophic status of the lake and its subsequent increase of trophic status. Currently, Maliszewskie Lake is a very shallow, declining reservoir. The initial period of its existence probably saw its maximal depth. In presented studies we compared our results with data from three other sites documenting the reaction of the lake environment during the Late Glacial and Holocene transformation. At that time we observed different reactions to the climate amelioration. In the northern, postglacial lakes, the Holocene warming at first provoked an input cold melting water characterized by more negative oxygen isotope values and then a rise in water temperature. In the lakes further away from the glaciation border (periglacial lakes), the increase in water temperature, documented by e.g. more positive oxygen isotopic immediately occurred. The climate warming is commonly manifested by a significant increase of number of species and individuals of Cladocera.

1. Introduction

Approximately 13,000 years ago the last natural drastic climate change started, associated with the transition from glacial (late glacial of the Vistulan (Weichselian) glaciation) to interglacial (Holocene) conditions. The environmental changes occurring during the Late Glacial/Holocene transform period are the subject of many paleolimnological studies (e.g., Apolinarska et al., 2012; Boettger et al., 2009; Bohncke and Hoek, 2007; Bos et al., 2007; Hammarlund et al., 2003; Lauterbach et al., 2011; Magny et al., 2006, 2007; Mirosław-Grabowska et al., 2015b; Moscariello et al., 1998; Schwander et al., 2000). At that time, rapid climate changes influenced the natural adaptations, such as changes in vegetation (terrestrial and aquatic) and lake conditions (temperature, trophic status, primary production, zooplankton development, water level). Analysing the palynological, faunal and geochemical data, we can see differences in the time, course and nature of this environmental response to changes and differences in their intensity. This reaction of the environment (terrestrial and aquatic) mostly depended on the distance from the maximal extent of ice sheet. It is worth adding that the limit of the maximum range of the last glaciation extended across Poland, which made it possible to observe the environmental reaction depending on the distance from the maximum range of the ice cover.

We present new results and interpretations of isotopic and cladoceran investigations of the Late Glacial and Holocene sediments of Maliszewskie Lake (NE Poland). Our goal was to establish the order and nature of the Late Glacial and early Holocene environmental alterations in Maliszewskie Lake. Moreover we wanted to compare our results with the data from other sites located at various distances from the maximal extent of the Vistulian glaciation ice sheet: Charzykowskie Lake

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(Mirosław-Grabowska and Zawisza, 2014), J-K paleolake (Mirosław-Grabowska et al., 2015a) and Romoty paleolake (Mirosław-Grabowska et al., 2015b). Therefore, we can observe the local reactions of the different (post- and periglacial) lake ecosystems to global warming.

The lacustrine sediments often contain authigenic carbonates and fossil shells. The stable isotope composition of the endogenic calcite that is precipitated biochemically as a byproduct of lake productivity has also proven to be a good source of paleoenvironmental and paleoclimatic information (e.g., Leng and Marshall, 2004; Lauterbach et al., 2011). The oxygen isotope composition of lacustrine carbonates is controlled by the isotopic composition of host water and the water temperature at which carbonate precipitation occurred (Craig, 1953; Hoefs, 1996; Schwalb, 2003). Two major processes may influence this composition. The first is evaporation, the intensification of which causes lake shallowing and enrichment in heavy isotopes (McKenzie and Hollander, 1993). The second process is an influx of fresh water into a lake, which causes its deepening and relative depletion of heavy isotopes (Talbot, 1990). The oxygen isotope composition of the lake water is determined by the atmospheric component of the global hydrological cycle (Hoefs, 1996; Różański et al., 1998). The lake water reflects the mean oxygen isotopic composition of catchment precipitation, which is primarily a function of latitude, modified by orography and continentality (Schwalb, 2003).

The carbon isotope composition of authigenic carbonates is determined by the isotopic composition of bicarbonate (HCO_3^-), which is the main form of dissolved inorganic carbon (DIC) in the lake water (Fritz and Poplawski, 1974). The ^{13}C content in sediments is mainly influenced by the exchange between CO_2 in water and the atmosphere, by the volume of incoming groundwater and the influx of dissolved carbonates, by plankton photosynthesis, and by CO_2 production during the decay of organic matter (Craig, 1953; Różański et al., 1998). Each lake is characterized by its own specific concentration of ^{13}C, depending on the degree of biological activity of aquatic plants in the lake, which is determined by climate (Wachniew and Różański, 1998).

Combining paleobotanical results with isotope data enables a more detailed paleoclimate reconstruction (Drescher-Schneider and Papesch, 1998; Mirosław-Grabowska, 2009; Mirosław-Grabowska, 2013; Mirosław-Grabowska and Zawisza, 2014; Mirosław-Grabowska et al., 2015b).

2. Maliszewskie Lake – Location and material

Maliszewskie Lake (53°10′23″N, 22°31′27″E) is located approximately 47 km west of Białystok (North Podlasie Lowland, E Poland) at 104.1 m a.s.l. (Fig. 1). It is a shallow overgrowing lake (ca. 80 ha, water depth of 1 m) surrounded by peatland. In 1982, Z. Balwierz and S. Żurek started the investigation of the 4.8-m-thick sediments of the Maliszewo I profile collected from the peatland (Balwierz and Żurek, 1987, 1989). The lowest part (4.62–4.83 m) of the Maliszewo I profile analysed was represented by fine grey sands with 1-cm-thick organic layers, containing a low amount of $CaCO_3$ (below 3%). Next, (depth: 4.55–4.62 m) brown-moss peat with gyttja appears (Fig. 2). The peat was covered (depth: 1.70–4.55 m) by calcareous light gyttja with a high amount of $CaCO_3$ to 92% (lake marl). The upper part of this succession contained a thin layer of sedge-moss peat (depth 1.60–1.70 m), detritus gyttja (depth 0.32–1.60 m) and then next layer of sedge-moss peat (to 0.32 m).

Z. Balwierz conducted a palynological analysis of these sediments using a standard method (Balwierz and Żurek, 1987). From the palynological results, 10 local pollen assemblage zones (Mal. I-1–10 L PAZ) were distinguished (Balwierz and Żurek, 1987).

In this paper, the results of investigation of the sediments from depth 1.3–4.7 m, which accumulated during the Late Glacial and early Holocene (only 8 local pollen assemblage zones (Mal. I-1-8 L PAZ)), are presented.

The radiocarbon dating of the studied sediments was based on the published six data (Balwierz and Żurek, 1989; Żurek et al., 2002). All of the conventional radiocarbon ages mentioned in the text were calibrated against the INTCAL13 calibration curve (Reimer et al., 2013).

The area of the Maliszewskie Lake is located in the transitional area between warmer lowlands of central Poland and cooler Podlasie region with a clear predominance of a continental influence. Therefore, the mean annual air temperature is 6.9 °C. The annual precipitation is ca. 570 mm. The mean temperature in the warmest month (July) is 17.6 °C. The mean temperature in the coldest month (January) is −5.3 °C. Westerly and south-westerly winds predominate (https://pl.climate-data.org/location/10086/).

The surroundings of Maliszewskie Lake are covered with cultivated meadows while the margin of this lake is overgrown by moss-sedge communities. Before the drainage, the central part of the peatbog was occupied by the communities of *Caricetum paradoxae* and *Caricetum fuscae*, the river-side parts by *Caricetum gracilis, Salici Franguletum,* and *Calamagrostietum*, and the lake shores by *Carici elongatae-Alnetum*. The surrounding plateaus are occupied by pine woods and mixed deciduous forests (Balwierz and Żurek, 1989).

3. Comparative sites

3.1. Charzykowskie Lake

Charzykowskie Lake is located at an elevation of 121 m a.s.l, near Chojnice, in the Tuchola Forest, northern Poland (Fig. 1). The lake is located in the northwestern part of the Brda outwash plain, which accumulated during the Pomeranian phase of the Vistulian glaciation approximately 16,200 year BP (Kozarski, 1995). The 6-m section of the bottom sediments, which accumulated during the Late Glacial and early Holocene, were the sediments studied for isotopic analysis and where the cladoceran were investigated by authors (Mirosław-Grabowska and Zawisza, 2014). The sediments consist of sandy silts at the bottom, followed (in upward succession) by gyttja characterized by increasing $CaCO_3$ content. The measured $\delta^{18}O$ values oscillate from −9.3 to −5‰ and $\delta^{13}C$ from −5.7 to +0.4‰. In the studied material, 24 taxa of the subfossil Cladocera belonging to five families and six phases (CAZ) of faunal development were identified. The sedimentation in Charzykowskie Lake started before 11,700 year cal BP (Mirosław-Grabowska and Zawisza, 2014).

3.2. J-K paleolake

J-K paleolake is situated at an elevation of 89.9 m a.s.l, in Kaniewo village, in the eastern part of the Kujawy Lakeland, central Poland (Fig. 1). It is located within the extent of the Vistulian (Weichselian) Glaciation ice sheet, approximately 15 km to the north of its maximum limit (Fig. 1). The sediment core of 4.1 m in length (J-K profile) was taken from the overgrown small lake and the sediments have still investigated. The deposits were composed mainly of silty sands on the bottom, and then of gyttja and lake marl. The uppermost sediment consisted of peat. The sediment core also recorded the vegetation composition that existed during the Allerød and Younger Dryas. These sediments represent the Late Glacial and the early Holocene accumulation (Mirosław-Grabowska et al., 2015a). Oxygen and carbon stable isotope analyses were conducted on samples of carbonate sediments. The values of $\delta^{18}O$ change from −10.8 to −4.4‰ and $\delta^{13}C_{carb}$ values oscillate between −3.2 to 1.2‰ (Mirosław-Grabowska et al., 2015a). Such a large range of isotopic data reflects changing conditions in the lake during the accumulation of deposits. The greatest variations occurred in the bottom sediments and were connected with the changing hydrological conditions during the transitional period. Analysis of subfossil Cladocera allowed identification of 27 species of Cladocera belonging to four families. Species composition and frequency of individuals allowed us to distinguish the five main stages of Cladocera fauna in the reservoir (Mirosław-Grabowska et al., 2015b).