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Limnological record inferred from diatoms in sediments of Lake Skaliska (north-eastern Poland)

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ABSTRACT. Subfossil diatoms analysis was employed to reconstruct past environmental changes in Lake Skaliska. This lake, presently a palaeolake, is located on a wide plain called the Skaliska Basin (northern part of Mazury Lake District, north-eastern Poland). Changes in terrestrial vegetation suggest that the initial phase of the lake was in the early Holocene. In the sediments a total of 176 diatom species belonging to 35 genera were identified. The majority of diatoms are alkaliphilous and alkalibiontic, occurring mainly in meso-eutrophic water. Diatom flora development suggests that the best conditions for diatom growth prevailed throughout the Boreal and in the early Atlantic, a suggestion supported by the increased frequency of planktonic diatoms living in nutrient-rich water. A water pH reconstruction (DIpH) based on diatoms points to alkalinity during the lake's existence. Since roughly the mid-Atlantic the lake was shallowing, and at the beginning of the Subboreal peat sedimentation led to complete overgrowth of the lake.

KEYWORDS: diatoms, trophy, water level, palaeolake, north-eastern Poland

INTRODUCTION

Diatoms are siliceous algae which occur almost in every type of ecosystem: lakes, seas, rivers, catchments, rocks, glaciers, etc. Due to their short life cycle they quickly respond to changes in their environment. Subfossil diatoms are used as indicators of environmental conditions (e.g. pollution, pH, nutrients, water level) and climate changes. The ratio between planktonic and benthic diatoms can be used to reconstruct lake-level changes.

A number of researchers have analysed diatoms from Holocene and Pleistocene sediments of north-eastern Poland (e.g. Marciniak 1973, Khursevich et al. 2005, Winter et al. 2008). In the present study the Quaternary evolution of Lake Skaliska, based on diatom analysis was examined. The origin of Skaliska Lake is connected with the melting of local glaciers at the end of the last glaciation. Pollen analysis indicates that the initial phase of the lake's existence was in Preboreal (Kołaczek et al. 2013). Several sediment cores were collected from the Skaliska Basin area. One of them is core W4 (Budzewo) drilled in the western part of this plain (Fig. 1). This core was chosen to represent the sediments for diatom analysis, because it was the longest of the cores collected from this region, containing a palaeobiological record of the greater part of the Holocene.

STUDY SITE

The Skaliska Basin (recently, palaeolake) is on a wide plain in the northern part of the Mazury Lake District (north-eastern Poland). The basin covers more than 90 km^2. It belongs to the Węgorapa District, which partly overlaps the Polish-Russian border. The central and northern parts of the palaeolake are at 95–98 m a.s.l., and the remaining area is at 100–115 m a.s.l. The Węgorapa

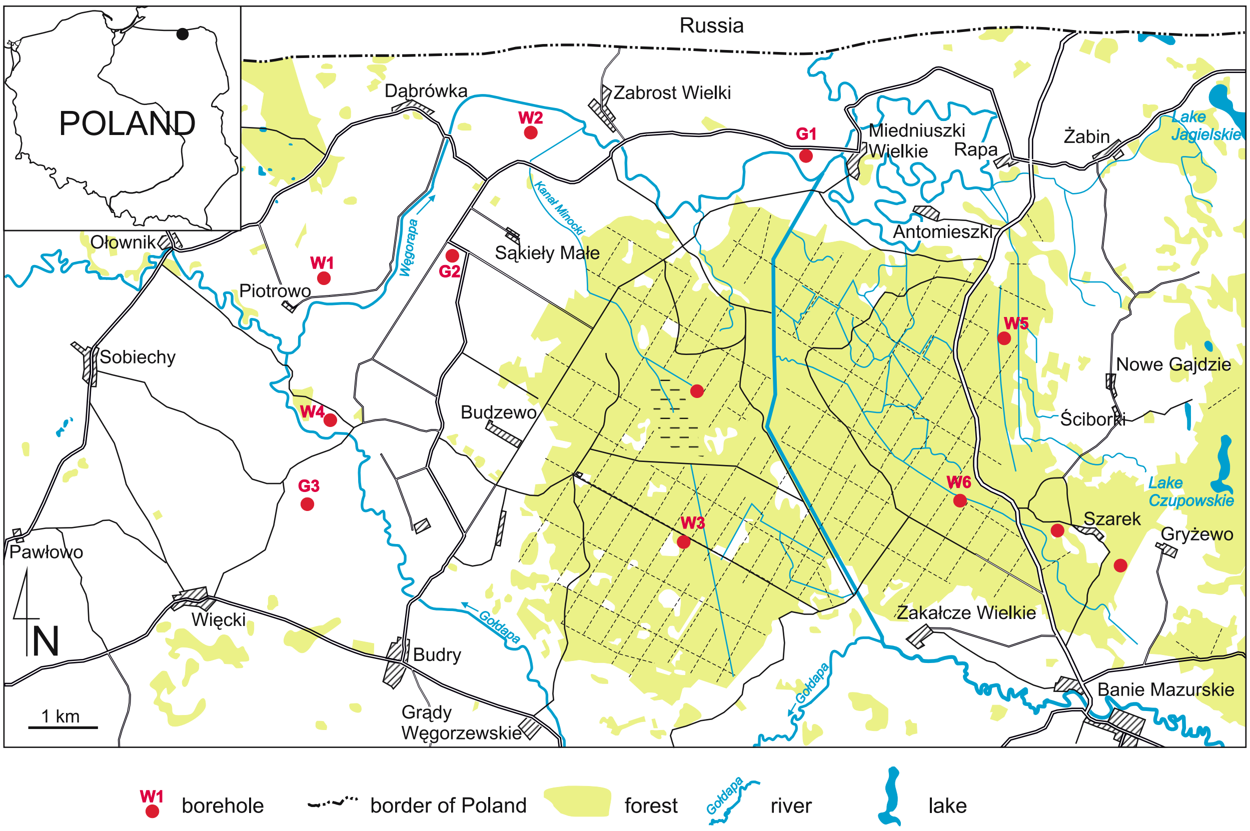

Fig. 1. Location of the collected cores from the area of the Skaliska Basin

and Gołdapa rivers flow through the Skaliska Basin in a relatively deep riverbed (up to 3 m) (Pochocka-Szwarc 2005). The eastern part of the palaeolake is surrounded by the Kruckie and Klewińskie hills; to the west and south is morainic upland with single kame hills (Stachowicz-Rybka & Obidowicz 2013).

METHODS

Core W-4 was collected with a Więckowski sampler (piston corer) in 2005. Fragments of wood and plant tissues from the lake sediments were radiocarbon-dated (Fig. 2); ^{14}C measurements were made in the Poznań Radiocarbon Laboratory by Accelerator Mass Spectrometer (95.4% probability). Radiocarbon dates were calibrated using Oxcal ver. 4.10 (Bronk Ramsey 2009).

Diatoms were analysed from gyttja sediments in the 980–220 cm depth interval (sampling resolution 20 cm). The remaining part of the core (bottom and upper layers) did not contain diatom valves. Preparation of diatoms from the sediment core followed standard methods (Battarbee 1986). In the laboratory, samples (1 cm^3 volume) were treated with 10% HCl to remove carbonate, then boiled in H_2O_2 until complete elimination of organic matter, and repeatedly washed with distilled water. Permanent slides were made with Naphrax® (R.I. = 1.75). More than 300 valves were counted per sample under an Olympus BX51 light microscope with an oil immersion objective at 1000×; the results are presented as a percentage diagram created with POLPAL (Walanus & Nalepka 1999). Identification of species follows Krammer & Lange-Bertalot (1986, 1988, 1991a, b) and Lange-Bertalot & Metzeltin (1996).

Reconstruction of pH was performed using the “Combined pH dataset” based on subfossil diatoms. This is a complex dataset derived from the following original datasets: Italian mountain lake dataset, Spanish mountain lake dataset, UCL mountain lake dataset, Norwegian dataset, Finnish dataset, Kola Peninsula pH dataset, SWAP dataset, and Swedish dataset (e.g. Catalan et al. 1993, Marchetto & Schmidt 1993, Larsen 2000, Birks et al. 2004). Reconstruction of pH was done by weighted averaging (WA) regression and calibration (ter Braak & Barendregt 1986). The diatom-pH transfer function resulted in a coefficient of determination (r^2) of 0.76 and root mean square error of prediction (RMSE) of 0.50. Only diatoms with percentages over 1% and at least three occurrences in the core were used to reconstruct pH.

RESULTS

A total of 38 samples for diatom analysis were studied from core W4 (Fig. 2). Altogether 176 diatom species belonging to 35 genera were identified. Planktonic as well as benthic diatoms preferring circumneutral and alkaline water occurred in the sediments. The most abundant taxa were alkaliphilous diatoms

(28–81% in the core). Alkalibiontic diatoms ranged from 8 to 34%, while the frequency of indifferent diatoms varied between 6 and 18%. The occurrence of acidophilous species did not exceed 5.5% in the core. Based on qualitative and quantitative changes in diatom frequency, four local diatom zones were distinguished (DAZ: DAZ 1 – DAZ 4). Division of the Holocene was based on palynological analysis (Kołaczek et al. 2013).

DAZ 1 (980–890 cm), Preboreal

This zone is dominated by small *Fragilaria* s.l. e.g. *Pseudostaurosira brevistriata* (Grun.) D.M. Williams & Round and *Staurosira construens* f. *venter* (Ehr.) Hamilton. Planktonic species such as *Aulacoseira granulata* (Ehr.) Simonsen and *Stephanodiscus hantzschii* Grunow reach less than 10% frequency.

DAZ 2 (890–590 cm), Boreal – early Atlantic

In this zone the dominant species is planktonic *Aulacoseira granulata*, which reaches more than 30% frequency in the middle part of it. Other planktonic diatoms such as *Cyclotella* s.l., *Stephanodiscus minutulus* (Kütz.) Cleve & Möller, and *S. hantzschii* reach their maximum occurrence, while benthic *Fragilaria* s.l. decreases.

DAZ 3 (590–310 cm), middle-late Atlantic – early Subboreal

This next zone is characterized by reduction of the share of planktonic diatoms versus benthic taxa. *Staurosira construens* Ehrenberg, *S. construens* f. *venter*, and *Staurosirella pinnata* (Ehr.) M.D. Williams & Round increase, while *Aulacoseira granulata* and *Cyclotella* s.l. decline in frequency.

DAZ 4 (310–220 cm), Subboreal

This zone is still dominated by *Fragilaria* s.l., but some planktonic diatoms increase. In the uppermost sample, *Cyclostephanos dubius* (Fricke) Round and *Aulacoseira ambigua* (Grun.) Simonsen reach frequency above 10%.

DISCUSSION

According to catchment vegetation, the origin of Lake Skaliska falls at the beginning of the Holocene (Kołaczek et al. 2013). Both planktonic and benthic diatoms occurred in these sediments. The majority of the diatom flora is typical of oligo-mesotrophic and eutrophic lakes. There is only a minor trend in the reconstructed pH values. Diatom-inferred pH varied between 8.1 (240 cm depth) to 7.6 (600 cm depth). The values are markedly constant (ca 7.8) in the studied sequence. The range of pH oscillation was only 0.5 pH units.

The initial period of the lake's existence (Preboreal, DAZ 1) was dominated by benthic and epiphytic diatoms such as *Fragilaria* s.l. and *Synedra ulna*. This suggests a shallow water level. Small *Fragilaria* s.l. often are pioneers in the early stages of late-glacial and post-glacial lake development (Solovieva & Jones 2002, Larsen et al. 2006). The cool climatic conditions are confirmed by palynological analyses (Kołaczek et al. 2013) and isotopic data (Mirosław-Grabowska 2013). Together with benthic and epiphytic taxa, diatoms preferring meso- and eutrophic conditions occurred at low frequency (e.g. *Stephanodiscus hantzschii*, *Aulacoseira granulata*, *A. ambigua*). The diatom assemblages indicate that the lake was oligo-mesotrophic at the beginning of its development.

Planktonic diatoms increased during the Preboreal/Boreal transition and the Boreal (lower part of DAZ 2). This indicates changes in environmental variables (e.g. rise of temperature) and a slight increase of water level. Climate warming is also shown by an increase of $\delta^{18}O$ (Mirosław-Grabowska 2013). The expansion of planktonic *Aulacoseira granulata*, *A ambigua*, and *Stephanodiscus minutulus* attests to a eutrophic environment.

At the beginning of the Atlantic (upper part of DAZ 2) the frequency of open-water diatoms increased. The development of planktonic *Cyclotella ocellata* Pantocsek, *Puncticulata radiosa* (Grun.) Hĺkansson, *Stephanodiscus hantzschii*, *S. minutulus*, and *Cyclostephanos dubius*, and the low frequency of benthic *Fragilaria* s.l., indicate higher water level. The dominant taxa in this part of the core point to a meso-eutrophic environment. On the other hand, the development of *Cyclotella* s.l. suggests a lower trophic status of the lake; the ecological amplitude of *Cyclotella ocellata* has not been entirely clarified, however. This taxon is found in shallow as well as deep ultra-oligotrophic (Wunsam et al. 1995, Cremer & Wagner 2003), oligo-mesotrophic (Reavie & Smol

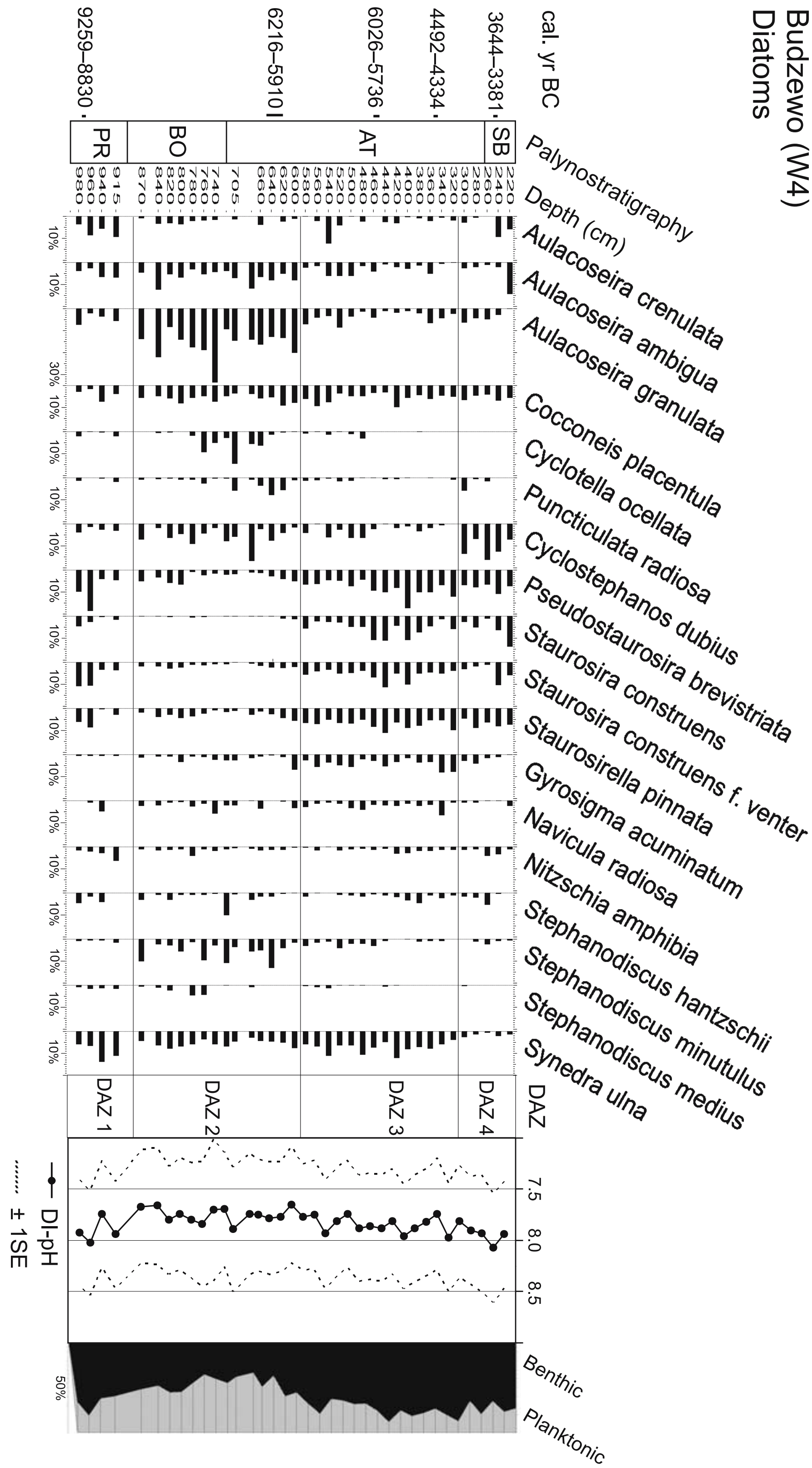

Fig. 2. Relative frequency diagram of the most dominant diatom taxa (>5% in any one sample) recorded in the sediments of the core W4 (Budzewo). Palynostratygraphy: **PR** – Preboreal, **BO** – Boreal, **AT** – Atlantic, **SB** – Subboreal

2001) and mesotrophic lakes (Wunsam et al. 1995, Gurbuz et al. 2003). *Puncticulata radiosa* rather occurs in mesotrophic water (Bennion et al. 2004). At this time the lake probably had good habitat conditions for promoting algal growth: warmer seasonal temperature and nutrient-rich surface water.

In the next part of the Atlantic (DAZ 3) most of the planktonic diatoms were replaced by benthic and epiphytic taxa. The frequency of *Staurosira construens* f. *venter*, *Gyrosigma acuminatum* (Kütz.) Rabenhorst, and *Cocconeis placentula* Ehrenberg is relatively stable and suggests shallow meso-eutrophic water. *Pseudostaurosira brevistriata*, *Staurosirella pinnata*, and *Synedra ulna* have wide trophy tolerance and can live in oligo-eutrophic water. However, they are diatoms occurring mainly on plants, sand, and rocks. Similarly, among the Cladocera remains benthic taxa dominate this part of the core (Gąsiorowski 2013).

The final phase of the lake's existence (Subboreal, upper part of DAZ 4) was still dominated by *Fragilaria* s.l. Almost certainly the water level was low, as marked by the decrease or disappearance of the majority of planktonic species. However, some planktonic species such as *Aulacoseira ambigua* prefer shallow lakes and dominate in meso- and eutrophic water (Manoylov et al. 2009). During this time, alkalibiontic *Cyclostephanos dubius* and *Aulacoseira ambigua* show relatively high frequency, probably as a response to increased nutrients in the lake. Gradually the frequency of alkalibiontic *Cyclostephanos dubius* fell slightly, perhaps due to lowering of the water level. It is likely that changes in hydrological and/or climatic conditions and the increased supply of organic matter from the catchment caused progressive shallowing of the lake.

CONCLUSION

Lake Skaliska existed from the Preboreal (Kołaczek et al. 2013). Both planktonic and benthic species occurred throughout the lake. Changes in water level were reconstructed based on the ratio between planktonic and littoral diatoms. Possibly the best conditions for growth of the diatom flora were during the Boreal and early Atlantic, marked by the highest development of diatoms living in open nutrient-rich water. The majority of diatoms were alkaliphilous and alkalibiontic taxa, confirming the high trophic status of the lake. Reconstruction of pH (DIpH) indicates that Skaliska Lake was alkaline throughout its history. Changes in the diatom community suggest that from about the mid-Atlantic the lake was shallowing. Finally a change in sediment lithology took place at the beginning of the Subboreal (220 cm). The deposits (gyttja) were replaced by peat accumulation, leading to gradual overgrowing of the lake.

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