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Climate driven changes in the submerged macrophyte and phytoplankton community in a hard water lake

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ABSTRACT

We studied the changes in the submerged aquatic vegetation (SAV) and phytoplankton community in a hard water lake during different meteorological conditions. We hypothesized that variations in climatic conditions (precipitation and temperature) can influence the physicochemical parameters of water and, in turn, affect SAV and phytoplankton development. The investigations were performed in Lake Rogóźno (the West Polesie region, Eastern Poland) over 10 years from 2003 to 2013. The physicochemical parameters, the structure of macrophytes and the phytoplankton community in the dry (2003–2006, DP) and wet periods (2007–2013, WP) were analyzed. Between the dry and wet periods, the water color and the concentration of dissolved organic carbon (DOC) increased considerably, whereas water conductivity decreased. Other parameters (concentration of nutrients, water reaction and transparency) were comparable during both periods. When the precipitation and water level were low (DP), charophytes dominated the SAV and cyanobacteria dominated the phytoplankton community. After the precipitation and water level increased (WP), the charophyte population declined and the vascular plants and bryophytes dominated. Furthermore, flagellated algae belonging to the dinophytes and cryptophytes were the most numerous in the phytoplankton community. These changes in the SAV and phytoplankton were linked with the variations of physicochemical parameters determined by the total precipitation and mean air temperature in March.

Introduction

Water level fluctuations induced by natural processes or human activity are considered to be one of the major factors affecting environmental conditions in lakes. The decrease in the water level, especially in shallow lakes, improves the light climate for submerged aquatic vegetation and also affects the abundance of phytoplankton (Blindow, 1992; Bucak et al., 2012; Haldna et al., 2008). Therefore, the controlled regulation of the water level can be a useful tool in lake management, e.g., the restoration of disturbed lakes, revegetation or the removal of nuisance macrophytes (Coops and Hosper, 2002; Rørslett and Johansen, 1996).

Changes in the water level have a variety of effects on the lake's ecological state. For example, rising of water levels in a humic lake can increase the hydration of the surrounding wetlands and forests, thereby intensifying the transport of dissolved organic carbon (DOC), including humic substances, from the catchment area into the water (Boyer et al., 1997; Klimaszyk and Rzymski, 2011). The humic substances are a heterogeneous mix of yellow- and brown colored compounds. Their concentration in natural waters is a very important factor affecting the functioning of the lake (Steinberg et al., 2006; Wetzel, 2001). Water runoff enriched with DOC from the upper soil layers can modify the trophic state of a lake and its phytoplankton community. An increase in the concentration of DOC increases water color and reduces water visibility, electrolytic conductivity, calcium and nutrient concentrations (Pęczuła and Szczurowska, 2013). The concentration of DOC in the water can vary considerably over the years, potentially stimulating changes in the lake ecosystems (Pace and Cole, 2002).

The concentration of humic substances in a lake can be correlated with the meteorological variability (Hongve et al., 2004), as precipitation often causes fluctuations in the water levels of lakes (Michalczyk et al., 2011). Therefore, the current climate changes can indirectly influence the physicochemical parameters of the water, including the DOC concentration. Significant positive trends in precipitation extremes over Europe since the middle of the 20th century (van den Besselaar et al., 2012; Zolina et al., 2009) and increasing trends of annual

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precipitation in Europe have been observed (European Environment Agency: http://www.eea.europa.eu). Conversely, snow cover duration, which can also affect the hydrologic regime, decreased in recent decades across Europe (Livingstone et al., 2010; Peng et al., 2013). In fact, in recent years, the concentration of DOC increased in the northern temperate lakes of Europe (Hongve et al., 2004; Vuorenmaa et al., 2006).

The influence of the water level on the water reservoirs and shallow aquatic ecosystems is well documented (Bucak et al., 2012; Wantzen et al., 2008); however, no data describing the effects of the fluctuating water level on deep, hard water lakes is available. This type of lake is usually nutrient poor and has relatively high concentrations of calcium, high water reaction, low phytoplankton biomass and high water transparency. In hard water lakes, charophytes occupy large portions of the bottom, and their development is related to light availability. They interfere with phytoplankton by enhanced sedimentation, reduced resuspension, nutrient immobilization and allelopathic effects (Berger and Schagerl, 2004; Kufel and Kufel, 2002; van den Berg et al., 1998). Nevertheless, charophytes are very susceptible to lake eutrophication, and they tend to disappear due to increased water turbidity (Blindow, 1992; Blindow et al., 2002).

The colonization or disappearance of charophytes in lakes, which can indicate environmental changes, has been observed many folds in long time perspective (Kłosowski et al., 2006; Sinkevičienė and Urbaitė-Maževič, 2012). The occurrence of charophytes in lakes is mostly affected by nutrient enrichment; however, many changes in this macrophyte group are not clearly correlated with increased lake trophy (Bociąg et al., 2011; Kłosowski et al., 2006). Due to the high sensitivity of charophytes to humic substances in water (Szmeja and Bociąg, 2004), we predicted that many transformations of the charophyte vegetation are governed by variations of the DOC concentration caused by natural, climatic factors.

In this study, we aimed to find a link between meteorological variability and changes in the submerged macrophyte and phytoplankton communities in a hard water, charophyte dominated lake. We hypothesized that variations in climatic conditions can influence macrophyte and phytoplankton development indirectly through the changes in the physicochemical parameters of water.

Materials and methods

This study was carried out in Lake Rogóźno (51°22′36″ N, 22°58′21″ E) in the Western Polesie region of eastern Poland. The lake is small (0.57 km^2), deep (mean depth of 7.4 m, max. depth of 25.4 m), dimictic and devoid of inflow and outflow. The catchment area (7.75 km^2) is mostly flat and its relative height is 9.2 m. Most of the catchment is occupied by arable areas (38%), forests (37%) and meadows (11%). The vegetation surrounding the lake is composed mainly of swampy alder forest (by the western lakeside) and coniferous forests with Scots pine (by the north eastern lakeside). From the 1950s until the beginning of the 21st century, Lake Rogóźno was characterized as a mesotrophic, hard water lake, with extensive charophyte vegetation (Ciecierska and Radwan, 2000; Fijałkowski, 1959; Sugier, 2008). The average water stage in the lake from 1991 to 2010 was 167.05 m a.s.l. with an amplitude of 0.64 m. The strong positive trend of increasing water levels in Lake Rogóźno, with an amplitude of approximately 0.6 m, was observed during the last 10 years (2003–2013) due to high precipitation totals during this period (Michalczyk et al., 2011). Since 2007, the water level in Lake Rogóźno has risen, and the large area of the lake catchment (approximately 0.05 km^2) has become more hydrated.

Data on air temperature and precipitation from a meteorological station in the town of Włodawa located in the Polesie region were accessed through an online climatological service (http://www.tutiempo.net). Because the water state in the lakes of the Polesie region is correlated with meteorological conditions (Michalczyk et al., 2011), the effects of the total precipitation during particular periods on the lake functioning were analyzed. The considered periods were as follows: three months before data sampling (from March to May), one hydrologic year (12 months from November to October before data sampling), one and a half hydrologic year (18 months from November to April before data sampling), two hydrologic years (24 months from November to October before data sampling) and three hydrologic years (36 months from November to October before data sampling). Additionally, the mean temperature of March was included in the analysis as a predictor of ice cover melting.

The studies of the phytoplankton biomass, chlorophyll-*a* concentration and physicochemical parameters of the water in Lake Rogóźno were carried out during the dry (2003–2006, DP) and wet periods (2007–2013, WP). The water samples were collected monthly (June–August) in 2003, 2005–2007, 2010 and 2013, excluding water hardness, which was determined in 2003, 2008 and 2013. Water samples for analyses were obtained using the Ruttner type water sampler (2.0 L capacity) from the water surface to the end of the euphotic zone at 1 m intervals and split into two collective samples: the first from 0.5, 1, 2 and 3 m (upper water layer) and the second from 5, 6 and 7 m (lower water layer). During the course of the field studies, selected physicochemical properties of the water, i.e., electrolytic conductivity (EC), water reaction (pH) and transparency by Secchi Disk visibility (SD), were measured.

In the laboratory, spectrophotometric analyses were used to determine the concentration of chlorophyll-*a* (Nush, 1980), total phosphorus (TP), total nitrogen (TN, Hermanowicz et al., 1999) and dissolved organic carbon (DOC) expressed as values of absorbance at 254 nm (Brandstetter et al., 1996). Water color was measured colourimetrically at 440 nm (converted to mg Pt L^{-1}; Lean, 1998), and water hardness was determined using the titrimetric method with disodium EDTA in mval L^{-1} (converted to mg $CaCO_3$ L^{-1}), according to Hermanowicz et al. (1999).

The samples for phytoplankton analysis were fixed with Lugol's iodine solution and a formalin glycerine mixture. The abundance of phytoplankton was determined according to Utermöhl's (1958) method and algal biovolume was calculated using the formula described by Hillebrand et al. (1999). The water samples were transferred to a settling chamber with a 5 ml capacity; after sedimentation, the algal abundance was evaluated using an inverted microscope (Zeiss Axiovert 135). In each chamber, small phytoplankton species were counted on the belts at 400× magnification (at least 200 individuals); larger forms (filamentous or coccal colonies) were counted on the entire bottom of the chamber at a magnification of 200×. The unit length of 100 μm and a surface of 300 μm^2 were considered to be one individual for filamentous and coccal colonies, respectively. Additionally, the samples for taxonomic analysis of phytoplankton were collected using a plankton net (20 μm mesh size) and were left without fixation in order to observe live specimens under a light microscope (Nikon Eclipse 80i).

The analysis of submerged aquatic vegetation (SAV) in Lake Rogóźno included the structure and distribution of the macrophytes in 2013 (during WP) and in the years 1999–2006 (including DP). In July 2013, 30 transects were staked out throughout the lake, each one situated from the lake margins to the maximum depth occupied by vegetation. The plant associations were determined according to the nomenclature of Matuszkiewicz (2001). The locations of particular plant communities in the lake were marked with a GPS receiver (Garmin 60Cx) and the plant community areas were calculated using the MapSource Trip & Waypoint Manager program and the bathymetric plan of the lake (Wilgat et al., 1991). Data on vegetation from 1999 to 2006 were taken