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Impact of historical land use changes on lacustrine sedimentation recorded in varved sediments of Lake Jaczno, northeastern Poland

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ABSTRACT

Varved lake sediments provide an invaluable archive of natural and human-induced environmental changes. We present results of sedimentological, geochemical and pollen analyses of recent sediments from Lake Jaczno (northeastern Poland). The sediment record was dated using varve chronology validated with ^{137}Cs fallout peaks. Principal Component Analysis (PCA) and stratigraphically constrained cluster analysis were used to identify four major phases of lake development during the last 200 years. These results were compared with maps and archival data. At the beginning of the studied period (1839–1853), the lake catchment was already partly deforested and used for agriculture, which resulted in intensive soil erosion and high input of minerogenic matter. Next, a short period (1854–1864) characterized by fire events is recorded by microcharcoal in the sediments. The following phase (1865–1971) shows major changes in the catchment area including further deforestation and shortening of the major inflow feeding the lake. This caused a major change from allochthonous (minerogenic) to autochthonous (biogenic) sedimentation, expressed by the transition from clastic-organic to biogenic varves. The most recent phase (1972–2013) is characterized by natural afforestation, reduction of allochthonous inputs and increase in autochthonous deposition. Our study shows how intensification of agriculture and related land use changes in small catchments influences sedimentation processes and the formation of varves.

1. Introduction

Along with climate, human activities play an important role in landscape transformation. Human-induced changes in land cover and of the hydrographical network have substantial impact on the environment. Recognition of past human activity and associated landscape changes has been of particular interest to evaluate their effects on nature and society (Swetnam et al., 1999). These processes can be investigated using natural archives with a support of documentary sources including historical maps (Hecky et al., 2003; Mazier et al., 2015; Veski et al., 2005). Such an approach is crucial for a better understanding of processes and effects of land use changes and help to assess their environmental impacts in the future (Tang et al., 2005).

One of the best known natural archives to track past land use changes are lake sediments (Last and Smol, 2001). They incorporate allochthonous material delivered from the catchment area by wind, mass movements, surface inflow, groundwater, as well as autochthonous material produced in the water column. This diversity of sediment sources allows to study changes in the catchment and their impact on the lake using numerous methods and indicators (Birks and Birks, 2006; Pędziszewska et al., 2015). Long-term processes related to human activity are precisely recorded by pollen spectra, diatom assemblages and geochemical composition of sediments (Miras et al., 2015; Rodríguez-Zorro et al., 2015). However, also short-term changes in the catchment may be recorded as sudden changes in sediment properties (Corella et al., 2011; Finsinger et al., 2006; Foucher et al., 2014; Theuerkauf et al. 2015). To fully understand the impact of past land use changes on lake sedimentation, high-resolution (decadal-to-annual) multi proxy investigations on well-dated sediment cores are necessary (Bonk et al., 2016; Czymzik et al., 2010; Kienel et al., 2013). In this sense, of particular importance are annually laminated sediments as they provide a reliable chronology in calendar years (Zolitschka et al., 2015).

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Northeastern Poland is rich in lakes which contain well-preserved laminated sediments (Tylmann et al., 2013). Some of them have already been investigated for reconstruction of land use changes and human impact (Gałka and Apolinarska, 2014; Kupryjanowicz, 2007; Madeja et al., 2010; Szal et al., 2014). However, all of these studies focus on long-term changes related to different phases of settlement in the region and vegetation dynamics, e.g. large-scale deforestation and expansion of arable lands related to introduction of new agricultural practices. Still, an open question is to what extent the recent (20th century) intensification of agriculture, especially in small and topographically diverse lake catchments which are abundant in northeastern Poland, impacted sedimentation processes in lakes (accumulation rates and composition of sediments).

Lake Jaczno, located in the Suwałki Lakeland, provides ideal conditions to answer this question. The lake has a small, agriculturally transformed catchment area and varved sediments occur in deep parts of the lake. These sediments were recognized in the 1960s for the first time (Więckowski, 2009) and the presence of varves in the topmost sediments was recently confirmed by Tylmann et al. (2013) and Butz et al. (2016). Thus, our goal in this paper is to assess the impact of historical land use changes in the catchment of Lake Jaczno on the formation of varves and chemical composition of sediments in this lake. Using sedimentological, geochemical and palynological analyses supported by precise dating, we investigate how human-induced changes in the catchment influenced sedimentation rates and the composition and structure of varves. These paleolimnological results are then compared with information derived from historical maps and documentary sources.

2. Study site

2.1. Present day situation

Lake Jaczno (53°51′18″ N, 21°57′07″ E) is situated in the Suwałki Lakeland in northeastern Poland (Fig. 1). Major landforms in this region developed during the Pomeranian Phase of the Weichselian glaciation about 15,200 years ago (Ber, 1982). The morphology of its catchment area features a characteristic postglacial landscape, with distinct changes in elevation and diverse glacial and glaciofluvial deposits (Fig. 2).

The catchment is aligned in a N-S direction with highest elevations (>280 m a.s.l.) in the northern and western parts and lowest (163.9 m a.s.l.) in the southern part (Figs. 2a, 2b). The surface of the catchment is characterized mostly by glacial tills and sands as well as fluvioglacial sands and gravels with addition of finer fractions and peat (Fig. 2c). The soil cover consists of cambisols and podzols in the northern part of the catchment and ferralic cambisols in the southeastern part. The central and northern parts of the catchment are predominantly used for agriculture while the southern and western parts are covered by forest (Fig. 2d). In vicinity of the lake dominant species are birch, alder and spruce. The northern basin of the lake is surrounded by steep (up to 20%) slopes prone to gully erosion. In smaller valleys and near the lake shore, peat and peaty mud occur. Lake Jaczno is fed mainly by a major inflow from the north. Additionally, several groundwater fed springs supply the northern basin while two periodic streams enter the western basin (Fig. 1). The Jacznówka river drains the water from Lake Jaczno southward to the Szeszupa river.

Lake Jaczno has a surface area of 40.6 ha and a maximum water depth of 25.7 m (Fig. 1). The lake basin can be divided into five subbasins with narrow connections overgrown by aquatic plants. The northern basin, from which the sediment cores were taken for this study, is the largest with an area of 23.2 ha and a maximum depth of 21.4 m. Seasonal field measurements of water column properties indicate a thermally stratified hardwater lake with at least seasonal anoxia in the hypolimnion (Butz et al., 2016). The present trophic status is described as mesotrophic (Górniak et al., 2007).

2.2. Historical background

Two villages situated in the area of Lake Jaczno catchment, Smolniki and Ługiele, were founded in the 17th century (Wiśniewski, 1965). Over the years the arrangement of farmlands has changed due to the development of agricultural techniques (Sokołowski and Szumiło, 1965). The area was partly deforested already in the 19th century. Major changes in cultivation techniques and related land use transformations took place in the Suwałki region in the years 1867–1877 and 1894–1909 (Kaczyńska, 1965). During the latter period, arable land occupied 55–60% and meadows constituted 20–25% of the catchment area. Further reduction of forest cover took place between 1915 and 1935 when ca. 30 ha of forest was cut in the western part of the catchment area (General'nyj Štab RKKA, 1935; Kartographische Abteilung d. Königl. Preuss. Landes Aufnahme, 1915). During World War II agriculture in this region suffered from substantial damage. In 1945 a regular parceling took place and large farms were divided between many owners. In the years 1946–1949 fallow lands were intensively cultivated and the

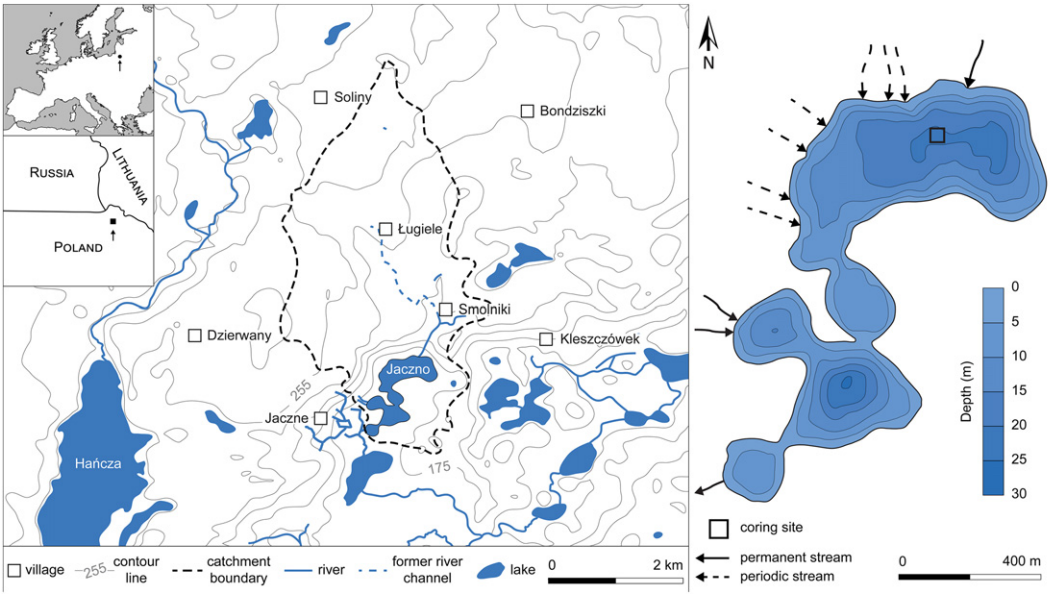

Fig. 1. Location and catchment area of Lake Jaczno in NE Poland and bathymetric map (provided by the Department of Limnology, Gdańsk University). Coring site is indicated.