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The response of flood-plain ecosystems to the Late Glacial and Early Holocene hydrological changes: A case study from a small Central European river valley

Dominik Pawłowski [a,*], Ryszard K. Borówka [b], Grzegorz Kowalewski [c], Tomi P. Luoto [d,e], Krystyna Milecka [c], Liisa Nevalainen [e], Daniel Okupny [f], Mateusz Płóciennik [g], Michał Woszczyk [h], Julita Tomkowiak [b], Tomasz Zieliński [a]

[a] Adam Mickiewicz University, Institute of Geology, Faculty of Geographical and Geological Sciences, Maków Polnych 16, PL 61-606 Poznań, Poland
[b] Geology and Paleogeography Unit, Faculty of Geosciences, University of Szczecin, Mickiewicza 18, PL 70-383 Szczecin, Poland
[c] Adam Mickiewicz University, Department of Biogeography and Paleoecology, Faculty of Geographical and Geological Sciences, Dzięgielowa 27, PL 61-680 Poznań, Poland
[d] University of Helsinki, Department of Geosciences and Geography, P.O. Box 64, FI-00014, Finland
[e] University of Jyväskylä, Department of Biological and Environmental Science, P.O. Box 35, FI-40014 Jyväskylä, Finland
[f] Institute of Geography, Pedagogical University of Kraków, Podchorążych St. 2, PL 30-084 Kraków, Poland
[g] Department of Invertebrate Zoology and Hydrobiology, University of Lódz, Banacha 12/16, PL 90-237 Lódz, Poland
[h] Adam Mickiewicz University, Institute of Geoecology and Geoinformation, Faculty of Geographical and Geological Sciences, Dzięgielowa 27, PL 61-680 Poznań, Poland

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ABSTRACT

We use a range of environmental variables to explore the possible drivers influencing the biota, especially the composition of aquatic invertebrates, during the Younger Dryas (YD) and Early Holocene (EH) in different river valley sites: a well-developed meandering river and the confluence zone of headwater streams. Using pollen, macrofossil, cladoceran, and chironomid as well as geochemical and lithological data as proxies for environmental factors (i.e., water depth and temperature), we attempt to show that these different sites display similar hydroclimatic signals (especially floods). The geochemical records in the studied valley are correlated with environmental factors, such as the evolution of the vegetation, the intensification phase of slope processes, and fluvial activities. Cladocerans and chironomids potentially play important roles in the recognition of flood episodes in the study sites, and any shift in their diversity and, especially, the co-occurrence of planktonic, sediment-associated cladocerans with rheophilic chironomids could be valuable indicators of floods and flow episodes. The variable changes in water levels at the sites reconstructed by the cladoceran-based water-depth model were positively associated with changes in lithophilic elements (K, Na, Al, Mg, and Ti), $SiO_{2(biog\ +\ ter)}$ and Fe/Mn, and our estimates of the paleohydraulic parameters for the study sites are generally consistent with changes in the composition of aquatic invertebrates. The recorded YD floods appear to be synchronous, regardless of the size and the different geological and geomorphological settings of each part of the river catchment. Our investigation demonstrates that flood magnitude increases in the downstream direction along the valley. The common increases in the water level at all study sites from the Grabia River valley are significant from 12,400 to 12,200 and from 11,900 to 11,800 cal BP and are comparable with those from elsewhere in Poland and Europe.

1. Introduction

In floodplains, oxbows and their biota are very sensitive to changes in humidity and to riverine influences, so these small lakes can play an important role in reconstructing and dating changes in humidity and even climate (Gandouin et al., 2007; Engels et al., 2008; Pawłowski et al., 2012). Their sediments are comparable to lake and mire sedimentary deposits for the study of past environmental change, especially in regions where lakes no longer exist, and in such cases, paleo-oxbow lake sediments are the only available archive or the archive of the best quality (Pawłowski et al., 2015a). Although paleo-oxbows have received much attention over the last half-century as indicators of changes in

* Corresponding author at: Adam Mickiewicz University, Institute of Geology, Faculty of Geographical and Geological Sciences, Palaeontology and Stratigraphy, Maków Polnych 16, PL 61-606 Poznań, Poland.
E-mail addresses: dominikp@amu.edu.pl (D. Pawłowski), ryszard@univ.szczecin.pl (R.K. Borówka), ichtys@amu.edu.pl (G. Kowalewski), tomi.luoto@helsinki.fi (T.P. Luoto), milecka@amu.edu.pl (K. Milecka), liisa.e.nevalainen@jyu.fi (L. Nevalainen), danek_1985@o2.pl (D. Okupny), mplociennik10@outlook.com (M. Płóciennik), woszczyk@amu.edu.pl (M. Woszczyk), geologia@univ.szczecin.pl (J. Tomkowiak), zielu@amu.edu.pl (T. Zieliński).

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fluvial systems, including the effects of major floods and droughts due to climate change (Van Huissteden et al., 1986; Rotnicki, 1991; Dambeck and Thiemeyer, 2002; Borisova et al., 2006; Schneider et al., 2007; Hoffmann et al., 2008), our knowledge of the paleohydrobiological functions of floodplains is scant compared to the extensive information we possess about paleo-lakes. Except for biological studies, little knowledge is available on the spatial variation in the zooplankton (e.g., Pawłowski, 2012; Płóciennik et al., 2015) of small paleo-oxbows. However, the formation and functioning of these lakes are closely dependent on the hydrological regime of their associated rivers, including floods (Petera-Zganiacz et al., 2015), and the flow regime combined with the physical and chemical parameters of the water body influence the zooplankton community (Schöll and Kiss, 2008). Velocity seems to be the most important variable for explaining the distribution of both invertebrate abundance and the number of taxa (Brooks et al., 2005), but water bodies on floodplains also have a natural buffering capacity (Simões et al., 2013). The influence of the river might enhance eutrophication, which is considered one of the most important factors contributing to the development of aquatic biota (Czerniawski and Domagała, 2012). This influence also temporarily lowers water transparency and enhances the accumulation of fine-grained clastic material and, consequently, the composition of aquatic invertebrate assemblages. For this reason, oxbows and the changes in the composition of their biota could serve as an indirect indicator of the fluvial activity in a valley. There are several environmental variables, such as water depth, summer water temperature, fish predation, macrophytes, nutrients, and sediment properties that have been noted as important forcing factors behind these invertebrate aquatic assemblages (cf. Davidson et al., 2010; Pawłowski et al., 2016). However, variations in the composition of zooplankton communities in different parts of a river valley could cause problems in interpretation. The ecological requirements, such as hydraulic microhabitats, and the geomorphological features of the river valley may be the major determinants of species diversity and abundance of the biota in floodplain habitats. Different water bodies in different parts of a river valley could thus have different habitats. To the best of our knowledge, there are no combined paleobiological and sedimentological studies from the whole of a river valley.

Paleo-oxbows in small river valleys, such as the Grabia River valley in central Poland, seem to be appropriate for such studies. Small rivers are just as sensitive to changes in humidity as large rivers (Pawłowski et al., 2015b). This results from the fact that the annual flow unsteadiness (i.e., the relationship of the maximum to the minimum or mean discharges) is larger for small than for large rivers (cf. Rotnicka and Rotnicki, 1988). Small rivers retain the hydraulic and geomorphological features typical of each part of the river but are not subject to the effects of the headwater section, which often have different hydrological characteristics. Unfortunately, there are only a few quantitative and semi-quantitative records of paleohydroclimatic and biotic responses with high temporal resolution from Central European river valleys (e.g., Pawłowski et al., 2015a).

This study includes a multiproxy analysis of paleo-oxbow and mire sediments, namely, pollen, plant macrofossil, Cladocera, Chironomidae, sedimentological, geochemical, and radiocarbon data from different parts of the same river valley. The aim of the study is to recognize and compare hydroclimatic signals (especially floods) in various parts of one Central European river valley by exploring the response of aquatic communities to long-term environmental changes during the Late Glacial and the Early Holocene and by evaluating which environmental factors can influence the dominance of specific aquatic invertebrate communities. These results are compared with sedimentological and geochemical data. We additionally use selected results (age-depth model, paleohydrological estimations, results of statistical analysis, and cladoceran-based water depth and temperature reconstructions) from our previous publications on the lower reaches of the Grabia River valley, at the Świerczyna site (Pawłowski et al., 2015a, 2015b), to recognize hydroclimatic events and to compare the inferred water-level changes with the main phases of fluvial activity elsewhere in Europe. These cladoceran-based water depth and temperature transfer functions are applied to Younger Dryas (YD) and Early Holocene (EH) oxbow lake sediments (Pawłowski et al., 2015b), and the results, compared with the chironomid- and pollen-inferred environmental changes, are very useful in recognizing hydroclimatic changes. However, cladoceran-based water level reconstructions have never before been tested on paleo-oxbow lake sediments from a single river valley in its entirety.

2. Study area

The analyzed sites at Grabica, Ldzań and Świerczyna are located in the central part of the Polish lowlands of the Łódź Region on the valley floor of the Grabia River (Fig. 1A, B). The source of the Grabia River is located at a height of 229.0 m above sea level, near the village of Grabica Kolonia. This river flows into the Widawka (within the Odra catchment) as its right tributary at 143 m above sea level. Its slope ($S = 0.9$ m/km) is moderate for a lowland river; the mean discharge in its lower reach is 4.2 m^3/s. The Grabia River channel is characterized by a sinuous (meandering) planform. River sinuosity decreases and the floodplain becomes marshy in the upper part of valley. The catchment basin covers 820 km^2 of agricultural and forested land (Maksymiuk, 1970). The majority of the floodplain in the Grabia River valley is occupied by a mire with peat pools and paleo-oxbow lakes, which are overgrown by riparian forests. Most of these mires and paleo-oxbows are located in cut-off paleochannels close to the Grabia stream, and they also have different surface areas. The contemporary water depths of the abandoned meander and peat pools of the Grabia do not exceed 2 m with a mean water depth of 0.5 m (Pawłowski et al., 2015a).

The ice sheet of the Saalian Glaciations (and particularly the Warthanian Cold Stage of the Odranian Glaciation) was the last to cover the Łódź Region. General descriptions of the geological setting of the Grabia Valley have been presented by Klatkowa (1987).

The Grabica mire lies near the village of Grabica Kolonia (Fig. 1B) at the headwaters of the Grabia River, approximately 2 km downstream from the source, inside a depression that is up to 10 m deep. The mire area is approx. 6 ha and its planform is nearly cordate (Fig. 1C). The floodplain surface lies at 215 m a.s.l., and Saalian till overlain by glaciofluvial sands and gravels surrounds the reach of the valley (Fig. 1C). A narrow sandy terrace (>20 m wide) of Weichselian age is located between the glaciogenic plain and the swampy floodplain. The floodplain succession consists of two packages: an approximately 1.5-m thick fluvial silt base topped by 0.3–2.0-m thick peat. Presently, the mire is dominated by alder swamp, but most of the catchment area is now agricultural land.

The Ldzań mire is located near the village of Ldzań in the middle reaches of the Grabia River valley (Fig. 1B), which is incised in the zone where Cretaceous bedrock (limestones and marls) dips southward from a nearly surficial position. These rocks are overlain by Pleistocene deposits with till on top (Fig. 1D). The valley succession begins from Saalian glaciofluvial gravels that pass upward to an approximately 20-m thick series of Weichselian fluvial sands. These build up the upper Grabia terrace to 5–10 m above the floodplain, and the terrace is frequently overlain by aeolian coversands and dunes. The floodplain succession consists of sands and silty sands and, locally, the gyttja and

Fig. 1. A–Location of the study site. B–The Grabia catchment: 1–river network: a–perennial rivers, b–ephemeral streams; 2–springs; 3–perennial swales (Maksymiuk, 1970, and this study); 4–documented mires; 5–study sites. C–Grabica. D–Ldzań. E–Świerczyna. C–E–digital elevation models (based on LiDAR data) of valley reaches with geological cross-sections. The geology of the Świerczyna area has been presented after Pawłowski et al. (2015a).