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Persist or take advantage of global warming: A development of Early Holocene riparian forest and oxbow lake ecosystems in Central Europe

Piotr Kołaczek [a, *], Mateusz Płóciennik [b], Mariusz Gałka [a], Karina Apolinarska [c], Kamila Tosik [b], Michał Gąsiorowski [d], Stephen J. Brooks [e], Monika Karpińska-Kołaczek [a, f, g]

[a] *Department of Biogeography and Palaeoecology, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University in Poznań, Krygowskiego 10, 61-680, Poznań, Poland*
[b] *Department of Invertebrate Zoology and Hydrobiology, University of Lodz, Banacha 12/16, 90-237, Łódź, Poland*
[c] *Institute of Geology, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University in Poznań, Krygowskiego 12, 61-680, Poznań, Poland*
[d] *Institute of Geological Sciences, Polish Academy of Sciences ING PAN, Research Centre in Warsaw, Twarda 51/55, 00-818, Warszawa, Poland*
[e] *Department of Entomology, Natural History Museum, Cromwell Road, London, SW7 5BD, United Kingdom*
[f] *Laboratory of Wetland Ecology and Monitoring, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University in Poznań, Krygowskiego 10, 61-680, Poznań, Poland*
[g] *Centre for the Study of Demographic and Economic Structures in Preindustrial Central and Eastern Europe, University of Bialystok, Plac NZS 1, 15-42, Białystok, Poland*

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A B S T R A C T

In this study, we focus on the environmental changes recorded in the San River valley (Stubno–Nakło site, south-eastern Poland) at the beginning of the Holocene. This multi-proxy study for the first time in the region of the northern foreland of the Western Carpathians included quantitative thermal reconstruction based on Chironomidae and high-stratigraphic resolution of ^{14}C AMS dating. We hypothesised that (i) climate events during the Early Holocene contributed to ecosystem turnovers via stimulating disturbances related to the river's fluvial activity and (ii) woodland and oxbow lake ecosystems became more resilient to flood disturbances along with the advance of forest succession on the floodplain. The results revealed that the response of ecosystems on the Early Holocene warming was strongly linked with the decrease in fluvial activity of the river. The reconstruction of the mean July temperature based on Chironomidae revealed the exceptionally high rate of warming during the period of ca. 11,490–11,460 cal. BP (at least 1 °C per decade) up to values > 2 °C than modern ones. During this period, the lake trophy and productivity started to increase with a simultaneous spread of *Betula* woodlands on the alluvial plain. The “Preboreal oscillation” cooling was dated at ca. 11,450–11,250 cal. BP. At that time, an increased climate instability led to a higher rate of extremal events such as flood at ca. 11,400–11,330 cal. BP, which probably led to the disruption of the *Betula* population. The development of riparian woodlands, initiated by the expansion of *Ulmus* from ca. 11,100 cal. BP, and further spread of *Quercus* and *Fraxinus excelsior* on the alluvial plain and lower river terraces increased plant transpiration and therefore limited the river runoff and its fluvial activity. This, together with the expansion of reed belt communities, probably limited the impact of floods on the oxbow lake. However, ca. 10,010–9880 cal. BP traces of higher fluvial activity, but of lower impact, were recorded.

1. Introduction

The transition between the Late Weichselian and Early Holocene (ca. 11,650 cal. BP, Rasmussen et al., 2014) was probably the time of the most dynamic environmental changes during the last 12,000 years in the Northern Hemisphere. The last Late Weichselian cold spell, Younger Dryas, being the cooling of strong amplitude, was followed by a period of rapid warming at the beginning of the Holocene (Rasmussen et al., 2014; Veski et al., 2015). The climate warming at the Younger Dryas–Holocene transition stimulated mass migration of temperate warm-demanding species to the north and to higher altitudes in mountains (Huntley and Birks,

* Corresponding author.
E-mail address: pkolacz@amu.edu.pl (P. Kołaczek).

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1983; Giesecke et al., 2017). This period revealed the strongest ecosystem turnover within the time frame 14,000–11,000 cal. BP as the recent study by Stivrins et al. (2016), restricted to the Baltic region, revealed. Simultaneously, the regional extinctions of arctic–alpine and glacial elements of flora and fauna and the rate of warming was comparable to that observed during the 20th and 21st centuries (Stivrins et al., 2016). Hence, the understanding of reaction of the Late Weichselian–Early Holocene ecosystems on climate changes may be crucial for deciphering ecosystem responses to modern climate changes and projections of future species' extinction patterns.

The climate warming at the Younger Dryas–Holocene transition contributed to transformations of middle latitude wetland and aquatic ecosystems. The impact of warming was distinct in changes of lacustrine algae microflora (e.g. Ralska-Jasiewiczowa et al., 2003; Stivrins et al., 2015) and submerged macrophytes (Gałka and Sznel, 2013; Gałka et al., 2014; Feurdean and Bennike, 2004). The river valleys, especially those running through mountain ranges in Central Europe, on one hand, provided shelter pockets in isolated valleys from harsh conditions for warm demanding taxa during cold spells; on the other hand, they might have been routes for migrating newcomers during warm periods (Kołaczek et al., 2018). The disturbance dynamics in river valleys not only determine the possibility of local biota persistence, but also influence a rate of new taxa invasions (e.g. Pyšek and Prach, 1993; Francis et al., 2006). Although the area of Central European Lowlands was studied in terms of river valley ecosystems' response to the Late Weichselian–Early Holocene climate changes (Turner et al., 2013; Pawłowski et al., 2016), there is still little known about the ecosystem transformations in river valleys running through the northern foreland of the Carpathian Mountains (Kołaczek et al., 2018). Despite numerous studies considering vegetation development and fluvial activity of rivers in that area during the Late Wechselian and Early Holocene (Gębica et al., 2015; and references therein), there is a deficiency of multi-proxy studies supported by reliable absolute chronologies (Kołaczek et al., 2017). Even if the palaeoecological profiles were dated using ^{14}C method, these dates were often carried out directly on bulk sediments (Gębica et al., 2015 and references therein), which enhanced the risk of obtaining dates older or younger than the real ones due to different types of contaminations (cf. Hatté and Jull, 2013).

In this study, we focus on the environmental changes, for the first time including quantitative thermal reconstruction, at the beginning of the Holocene in south-eastern Poland recorded in the palaeomeander situated in the San River valley. The site as the first in the region of the northern foreland of the Western Carpathians has an established absolute chronology based on the high stratigraphic resolution of ^{14}C AMS dates (6 dates per 1 m of the profile) (Kołaczek et al., 2017). Moreover, the time span of the profile, ca. 11,550–9800 cal. BP (Kołaczek et al., 2017), gave us the possibility to have a closer look at the other Early Holocene climate events such as "Preboreal oscillation" or 11.1 and 10.3 ka Bond's events (Bond et al., 1997, 2001). We hypothesise that (i) climatic events during the Early Holocene contributed to the ecosystem turnovers via stimulating disturbances related to river's fluvial activity and (ii) woodland and oxbow lake ecosystems became more resilient to flood disturbances together with the advance of forest succession on the floodplain. The main aims of our study are to reconstruct: (i) the characteristics and impact of the Early Holocene climatic events on woodland and oxbow lake ecosystems, (ii) timing and the reaction of riparian forest succession on climate changes, and (iii) development of oxbow lake ecosystem with its potential influence on thermal reconstruction inferred from Chironomidae. To study these problems, we applied a multi-proxy analysis combining pollen, non-pollen palynomorphs (NPPs), plant macrofossil, microscopic charcoal, molluscs, Chironomidae, Cladocera, stable isotopes of carbon and oxygen from carbonates, stable isotopes of carbon and nitrogen from organic matter, and the content of organic carbon, nitrogen and sulphur. Such diversity of analyses applied to a single site is a novel approach in the palaeoecological studies in the northern foreland of the Carpathians and one of few applied to the reconstruction of oxbow lake ecosystem in this part of Europe (cf. Turner et al., 2013; Pawłowski et al., 2016; Kołaczek et al., 2018).

2. Site setting

The Stubno–Nakło (S–N 1b profile; core site: 49°51′47″N, 22°58′08″E; 186.5 m a.s.l.) site is located in the eastern part of the Sandomierz Basin—a vast depression limited by the Carpathian Mountains to the south, the Małopolska Upland to the west and north-west, Roztocze to the east and north-east and the Lublin Upland to the north (Kondracki, 2002). The S–N site is the palaeomeander (meander radius: 300 m and channel width: 100 m) located in the San River valley within the Late Glacial flood basin limited to the west by wide natural levees cut by a system of younger palaeomeanders of the San River (Fig. 1). The Holocene floodplain of the San River valley in the S–N palaeomeander area reaches a width of 10 km and rises 6–8 m above the river channel (Klimek et al., 1997; Kołaczek et al., 2017).

The climate of the area is classified as cold temperate with mean annual air temperature +8.2 °C and mean annual precipitation 620 mm. A mean temperature of the warmest month, i.e. July, is +18.2 °C, whereas a mean temperature of the coldest month, i.e. January, is −3.6 °C (https://pl.climate-data.org/).

The area is dominated by chernozems, brunisols and silt soils developed on loess, sands and silts, which are mainly used as cultivated fields, mown meadows and pasturelands (Dobosiewicz, 2008). The area of palaeomeander is exploited as a cultivated field and was partly adapted to a drainage ditch.

3. Material and methods

3.1. Fieldwork, lithology, absolute chronology and sediment accumulation rate (SAR)

The 500-cm-long core (labelled as S–N 1b) was retrieved in 2014 using an "Instorf" sampler (Russian type; chamber dimension: 6 × 50 cm) from the area with the greatest thickness of deposits within the former oxbow lake. For the purpose of this study, the section between the depths of 500 cm and 300 cm was selected. Within the selected section, seven lithological units were distinguished (Table 1) (Kołaczek et al., 2017).

An absolute chronology based on a Bayesian age-depth model was calculated on the basis of 10 out of 12 AMS ^{14}C dates (Fig. 2). For better readability of the modelled dates in the text, μ values rounded to tens were selected and expressed as cal. BP (the year before AD 1950). The analysed part of the profile spans a period between ca. 11,550 ± 80 and ca. 9770 ± 170 cal. BP (±σ error). The σ error of the modelled ages ranged between ca. 40 and ca. 170 years. The SAR values varied between ca. 0.03 and ca. 1.23 cm year^{-1} (Fig. 2). The age-depth model was slightly modified in comparison with Kołaczek et al. (2017) in which a laboratory error of the Poz-66934 date was erroneously increased. However, the modelled dates calculated from the final model were within σ error, in comparison to the model published by Kołaczek et al. (2017).

3.2. Biotic proxy and microcharcoal analyses

A detailed description of the methods for pollen, NPP, plant