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# Unveiling exceptional Baltic bog ecohydrology, autogenic succession and climate change during the last 2000 years in CE Europe using replicate cores, multi-proxy data and functional traits of testate amoebae

Mariusz Gałka [a,*], Kazimierz Tobolski [a], Łukasz Lamentowicz [b], Vasile Ersek [c], Vincent E.J. Jassey [d,e], Willem O. van der Knaap [f], Mariusz Lamentowicz [a,g]

[a] Department of Biogeography and Palaeoecology, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University in Poznań, B. Krygowskiego 10, 61-680 Poznań, Poland
[b] Faculty of Biology, Adam Mickiewicz University, Umultowska 89, 61-614 Poznań, Poland
[c] Department of Geography, Northumbria University, Newcastle upon Tyne NE1 8ST, UK
[d] Swiss Federal Research Institute-WSL, Community Ecology Research Unit, Station 2, CH-1015 Lausanne, Switzerland
[e] École Polytechnique Fédérale de Lausanne (EPFL), School of Architecture, Civil and Environmental, Engineering (ENAC), Laboratory of Ecological Systems (ECOS), Station 2, CH-1015 Lausanne, Switzerland
[f] Institute of Plant Sciences and Oeschger Centre for Climate Change Research, University of Bern, Altenbergrain 21, CH-3013 Bern, Switzerland
[g] Laboratory of Wetland Ecology and Monitoring, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, B. Krygowskiego 10, PL–61 680 Poznań, Poland

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ABSTRACT

We present the results of high-resolution, multi-proxy palaeoecological investigations of two parallel peat cores from the Baltic raised bog Mechacz Wielki in NE Poland. We aim to evaluate the role of regional climate and autogenic processes of the raised bog itself in driving the vegetation and hydrology dynamics. Based on partly synchronous changes in *Sphagnum* communities in the two study cores we suggest that extrinsic factors (climate) played an important role as a driver in mire development during the bog stage (500–2012 CE). Using a testate amoebae transfer function, we found exceptionally stable hydrological conditions during the last 2000 years with a relatively high water table and lack of local fire events that allowed for rapid peat accumulation (2.75 mm/year) in the bog. Further, the strong correlation between pH and community-weighted mean of testate amoeba traits suggests that other variables than water-table depth play a role in driving microbial properties under stable hydrological conditions. There is a difference in hydrological dynamics in bogs between NW and NE Poland until ca 1500 CE, after which the water table reconstructions show more similarities. Our results illustrate how various functional traits relate to different environmental variables in a range of trophic and hydrological scenarios on long time scales. Moreover, our data suggest a common regional climatic forcing in Mechacz Wielki, Gązwa and Kontolanrahka. Though it may still be too early to attempt a regional summary of wetness change in the southern Baltic region, this study is a next step to better understand the long-term peatland palaeohydrology in NE Europe.



## 1. Introduction

Understanding the impact of past climate change on ecosystems is critical for predicting the response of ecological communities to on-going climate change (Blois et al., 2013; Lyons et al., 2016). Although climatic forcing is not obvious in many archives, peatland records show both extrinsic (allogenic) and intrinsic (autogenic) processes. The drivers controlling the development of peatlands are often difficult to identify and disentangle because past climate changes are often mixed up with human impacts (Hughes et al., 2008). As suggested by Swindles et al. (2012), autogenic processes might be underestimated as drivers of peatland

* Corresponding author.
*E-mail address:* galka@amu.edu.pl (M. Gałka).

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development. In addition, it should be stressed that not much is known about the development mechanisms of continental peatlands which cover large surfaces of the northern Hemisphere and are therefore key areas of carbon accumulation.

Until now, two theories have been put forward to explain the ombrotrophic development of peatlands. In the first, presented by Osvald (1923) and Kulczyński (1949), the development of local vegetation, mainly of *Sphagnum*, was regarded as a cyclic regeneration of bog microforms by regular alternation of hummocks and hollows. The second theory holds that the development of ombrotrophic mires is closely associated with climate change (Barber, 1981; Schoning et al., 2005; Charman et al., 2006). During wet climatic phases, wet-adapted plant species like *Sphagnum cuspidatum, S. balticum* and *Scheuchzeria palustris* emerge and dominate the system by creating wet lawns or hollows. In contrast, dry climatic stages lead to the development of plant communities dominated by *Sphagnum fuscum, S. rubellum* or *Calluna vulgaris,* that usually occur in dry microforms such as hummocks (Hölzer, 2010; Laine et al., 2011). Therefore, shifts between species of wet and dry habitats can be used as indicators for changes in climate. (Sillasoo et al., 2007; Valiranta et al., 2012). Cyclical development of raised bog vegetation has not been proven so far, despite the fact that various authors studied the potential signal of solar activity in peat records (Mauquoy et al., 2004, 2008). However, Turner et al. (2016) warned that one should be very careful in interpreting such data, because solar-type signals might be the product of random variations. Consequently, recent palaeoecological research and palaeohydrological reconstructions from ombrotrophic peatlands in southern Finland (Tuittila et al., 2007), northern–eastern Europe (Swindles et al., 2012), and Patagonia (Loisel and Yu, 2013) show that the mechanisms of peatland development can be very complex. Human pressure on peatland ecosystems, like drainage, fires, deforestation in their catchment or deposition of minerals and nitrogen on peatland surfaces can indeed lead to disturbances in peatland development (Hughes et al., 2008; McClymont et al., 2008; Gałka et al., 2015; Swindles et al., 2015). Such disturbances bring additional difficulties to disentangle climatic impact from autogenic succession.

In this context, Baltic raised bogs are a good model ecosystem to study local vegetation development and its relationship to climate changes, because they possess an undisturbed history of vegetation development and peat/carbon accumulation (Barber et al., 2004; Gałka et al., 2016; Mathijssen et al., 2016). But even though many of these valuable ecosystems are protected by law, their development and response to climate change are still poorly understood. These bogs are of particular importance for research because in many areas of the world the natural peat dynamics in bogs have been profoundly modified by anthropogenic influences (Chambers et al., 2013). In the last 200 years, almost all bogs in Europe have been modified by human action (Joosten and Clarke, 2002).

Multi-proxy studies of Baltic raised bogs (including macrofossils, testate amoebae, pollen, micro- and macro-charcoal, isotopes and peat characteristics) covering a range of time spans and focused on various palaeoecological aspects have been conducted in Sweden (van der Linden and van Geel, 2006; Andersson and Schoning, 2010), Finland (Tuittila et al., 2007; Väliranta et al., 2007), Estonia (Sillasoo et al., 2007), Poland (Gałka et al., 2013, 2014a, 2015, 2016; Lamentowicz et al., 2008, 2009, 2015), Germany and Denmark (Barber et al., 2004). Testate amoebae are widely used for estimating past water tables and trophic state in peatlands (Charman, 2001; Mitchell et al., 2008). These fossil protist assemblages are up to today the only source of quantitative data from raised bogs that have been used for regional palaeohydrological syntheses (Charman et al., 2006; Swindles et al., 2013). Recently, functional traits of testate amoebae became important in palaeoecological reconstructions from peatlands (Kajukało et al., 2016; Lamentowicz et al., 2015; Fournier et al., 2015). This novel and promising approach offers the potential to study peatland ecosystem functioning on long time scales based on a more generalised interpretation of testate amoeba morphology and functional diversity.

However, despite previous multi-proxy studies, our knowledge of continental ombrotrophic peatland development is still unsatisfactory (Gałka, 2011). High-resolution, long-term studies with replicate cores are currently not available for the central-eastern European region and very scarce in the rest of the world (but see Lamentowicz et al., 2011; Gałka et al., 2016). Here, we aim to i) reconstruct local and regional vegetation changes in Mechacz Wielki bog; ii) reconstruct long-term peatland ecosystem dynamics using testate-amoeba functional traits and diversity; iii) compare the palaeohydrological signal in this bog with that in other Baltic raised bogs; iv) evaluate the relative importance of climatic influence and autogenic succession in the development of the bog; and v) reconstruct the former *Sphagnum* communities in the bog and assess their resilience to disturbance, as an aid in further protection and management of the area. Specifically, we tried to answer the question whether local vegetation and hydrology (including testate-amoeba communities and functional traits) during the last 2000 years were driven either by regional climate change – i.e. extrinsic control- or by autogenic development (succession) of peatland microforms – i.e. intrinsic control.

## 2. Study site

We selected Mechacz Wielki bog (northeastern Poland, Fig. 1) for two reasons. First, the site, despite some drainage in the 1960s, preserves its natural character, which is very rare in this part of Europe. Remains of the pristine ombrotrophic plant communities with the very rare *Sphagnum fuscum, S. cuspidatum* or *Rubus chamaemorus* (typical for the Baltic bog vegetation) still occur within the bog, which is the reason for its protection. Human activity in this region was very low due to low industry and settlement development and increased only ca. 1700 CE, so we can exclude human impact on the bog ecosystem before that time (Gałka et al., 2014b). Second, Mechacz Wielki bog is located at the southern distribution limit of Baltic raised bogs, which are shaped by the climatic influences of both western oceanic and eastern continental air masses.

Mechacz Wielki bog is a nature reserve with an area of peatland of approximately 146.72 ha. The peatland is located within the large Romincka Forest complex, a major portion of which is located in the Russian Federation. The peatland was drained in the 1960s, but was later restored by a system of dams on ditches. This area was affected by the last (Vistulian) glaciation (Krzywicki, 2002) and the relief is characterised by numerous morainic and kame hills, with a height of approximately 200 m a.s.l. The hills are composed of silty clays, glacial sands and erratic boulders (Krzywicki, 2002). The highest point in the vicinity of the peatland is 295.4 m a.s.l. and the lowest 150 m a.s.l.

The influence of the continental climate is very clear in the study area. Mean temperature is approximately −5 °C in January and +16–17 °C in July (Woś, 1999), while the mean annual temperature is +6.4 °C, and the precipitation reaches 700 mm annually. The vegetation of the peatland has a highly mosaic character. Only the central part of the peatland has raised bog vegetation and is overgrown with dwarf pine. Part of the peatland has hummock–hollow structures. The hummocks are dominated by *Sphagnum magellanicum, S. rubellum,* and *S. fuscum,* in addition to *Eriophorum vaginatum, Andromeda polifolia,* and *Oxycoccus palustris. Empetrum nigrum* and *Rubus chamaemorus* are less numerous on