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# Abrupt ecological changes in the last 800 years inferred from a mountainous bog using testate amoebae traits and multi-proxy data

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## Abstract

Mountainous peatlands of Western Sudetes are considered a unique habitat in Central Europe. The region contains one of the largest raised bog complexes in temperate Europe and is thus of great importance for biodiversity conservation. In this first high-resolution study from this region we use long-term ecological data to assess how these mountain wetland ecosystems responded to anthropogenic impacts and climate change. We used testate amoebae morphological traits, micro- and macroscopic charcoal, pollen and plant macrofossils to reconstruct the history of peatland development over 800 years, illustrating shifts in its development and fire dynamics. Five hydrological stages of peatland development were recognized. Testate amoebae morphological traits reflected several abrupt ecological changes linked to anthropogenic modifications of landscape openness. A shift towards mixotrophic taxa, linked to hydrological change or shrubs expansion and shading, preceded aperture position change, which was associated to dust input through surrounding deforestation and simultaneous water-table increase. Fire reconstruction revealed increasing burning together with intensifying human activity, including the expansion of a nearby settlement. This study confirms the potential of testate amoeba communities and the use of morpho-functional traits as indicators of ecological effects of land-use change over long-temporal scales.


***Keywords:*** Fire history; Ombrotrophic peatland; Palaeohydrology; Poland; Testate amoebae; Trait-based palaeoecology

## Introduction

Peatlands are vulnerable to changes in external conditions (Charman, 2002; Rydin and Jeglum, 2006) and are responsive to both global climate change (Tarnocai, 2006) and local environmental variations (Marcisz et al., 2015; Olsson et al., 2010). Mountain peatlands are functionally and structurally different from lowland and upland mires; they are often much smaller and are typically located in steeply sloping, thus well-drained areas (Bragg, 2015). In developed regions such as central Europe, the impact of human activities on peatlands is generally lower and more recent in the mountains than in the lowlands. Good examples of this are the peatlands of the Izera Mountains in the Western Sudetes on the border between the Czech Republic and Poland. The early development of these ombrotrophic peatlands was entirely dependent on natural factors while human disturbance became the most significant driver of change in the past millennium (Fiałkiewicz-Kozieł et al., 2015).

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Due to a peatlands' ability to accumulate a continuous archive of micro- and macrofossils, it is possible to reconstruct former peatland dynamics (Birks and Birks, 1980); therefore, by looking at their past, we gain perspective on the factors contributing to their present state (Seddon et al., 2014). Testate amoebae (TA) are one of the most important group of bioindicators in peatland palaeoecology (Mitchell et al., 2008a). These unicellular protists are abundant in various environments, including surface mosses in peatlands, and their tests are generally well preserved in peats (Meisterfeld, 2001). Modern peatland TA assemblages are best correlated to local hydrology (especially water table depth) and water chemistry (especially pH) and subfossil communities can thus be used as proxies to infer these variables using transfer functions (Charman, 2001). Furthermore, morphological and functional traits of TA were shown to be related to environmental process and gradients. In addition to inference of individual abiotic variables, which has long been possible using taxonomic approaches, TA traits can provide information about past changes in ecosystem functioning (Fournier et al., 2015; Lamentowicz et al., 2015). This represents a new development in palaeoecology (Blois et al., 2014).

Multi-proxy palaeoecological studies are often considered to provide a more comprehensive and robust information on mire history than single proxy studies, possibly allowing to disentangling the relative influences of autogenic succession from climatic and anthropogenic allogenic signals (Birks and Birks, 2006; Blundell et al., 2008; Charman, 2001; Lamentowicz et al., 2009b). Such studies involving quantitative reconstructions from TA have been performed on a number of Polish Baltic raised bogs located in the moraine plateaus (Gałka et al., 2015; Lamentowicz et al., 2015, 2009b, 2008). However, it should be stressed that mire ecosystem response to environmental changes may vary according to the specific local conditions (Sjögren and Lamentowicz, 2007). For this reason, studies from multiple sites within regions are needed (Charman et al., 2006; Swindles et al., 2013). Special attention should be paid to mountain peatlands, which are particularly vulnerable to global change (Beniston et al., 1996). Climate change may lead to perturbations in mean precipitation patterns, shifting water supplies, runoff and intensifying soil erosion. Particularly snowpack, the main component of the hydrological cycle in mountain regions, is predicted to respond rapidly to changes in temperature, what would shift water availability for hydrological basins (Beniston, 2003). Notwithstanding, palaeoecological multi-proxy studies including TA are relatively rarely carried out in peatlands in mountains (Dudová et al., 2012; Lamentowicz et al., 2010; Mitchell et al., 2001; Swindles et al., 2010).

We present the first complex study conducted in one of the largest mountainous raised bog complexes in temperate Europe, Izera River valley, Poland/Czech Republic. Only limited quantitative palaeoecological data exist for this peatland (Fiałkiewicz-Kozieł et al., 2015; Skrzypek et al., 2009) and hence, little is known about its development history. The site plays an important role in water retention, carbon storage and biodiversity conservation by providing habitat for many threatened species of flora and fauna. However, recent extreme atmospheric pollution has heavily impacted the forests and soils of this region. We combined the results of TA (using both taxonomic and trait-based approaches), charcoal analysis, plant macrofossils and pollen to provide a high-resolution palaeoecological reconstruction of the history of this *Sphagnum* bog. One of our main goal was to determine the role of human influence on the ecosystem of the Izera Mountains peatlands as the settlement history nearby Jagnięcy Potok peatland is well documented by historical sources (Skowroński, 2010). A broad range of anthropogenic impacts have influenced peatland ecosystem. Human activities in this region varied over the years and ranged from deforestations, land-use changes including settlements establishment, increased fire activity, inappropriate forest management to industrial development resulting in severe atmospheric pollution (Kolář et al., 2015; Speranza et al., 2000). Related environmental changes included hydrological cycle shifted by increased runoff, decreased evapotranspiration and water-retention capacity, vegetation changes and wildfire occurrences (Dudová et al., 2012; Kolář et al., 2015). Regional changes resulted in water table fluctuations on the peatland, altering microbial communities and vegetation.

The aims of the study are as follows: (1) to reconstruct the past hydrology of the mire using a peatland TA transfer function and their morphological traits, (2) to reconstruct fire dynamics on the peatland and its surroundings using charcoal analysis, and (3) to infer palaeohydrological and trophic fluctuations connected with land-use changes and fire activity.

## Material and Methods

### Study site

Jagnięcy Potok peatland (50°51′08″ N, 15°21′36″ E) is located in south-west Poland, close to the border with the Czech Republic (Fig. 1). It covers an area of about 14 ha, and it is a part of a greater complex of mires formed within the Izera River valley in the central part of the Izera Mountains (Tołpa, 1949). The investigated site is an ombrotrophic bog which developed in specific environmental conditions combining gentle relief features, altitude (elevation 850 m a.s.l.), impermeable granitic and granitic-gneiss bedrock, and cool, moist climate (Potocka, 2002). Presumably, the complex originated in a river valley as a minerogenous mire, but the growing peat layer isolated the surface from the effect of groundwater and the bog stared to receive water through precipitation alone.

Average annual temperature is 4.5 °C. The coldest month is January, with a mean temperature −7.5 °C, whereas the average temperature of July, the warmest month, reaches 15.0 °C (Potocka, 1996). The mean annual precipitation sum is above 1500 mm. Precipitation is evenly distributed throughout the year with a slight peak in summer and a minor secondary