



Long-term hydrological dynamics and fire history over the last 2000 years in CE Europe reconstructed from a high-resolution peat archive



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ABSTRACT

Sphagnum peatlands in the oceanic-continental transition zone of Poland are currently influenced by climatic and anthropogenic factors that lead to peat desiccation and susceptibility to fire. Little is known about the response of *Sphagnum* peatland testate amoebae (TA) to the combined effects of drought and fire. To understand the relationships between hydrology and fire dynamics, we used high-resolution multi-proxy palaeoecological data to reconstruct 2000 years of mire history in northern Poland. We employed a new approach for Polish peatlands – joint TA-based water table depth and charcoal-inferred fire activity reconstructions. In addition, the response of most abundant TA hydrological indicators to charcoal-inferred fire activity was assessed. The results show four hydrological stages of peatland development: moderately wet (from ~35 BC to 800 AD), wet (from ~800 to 1390 AD), dry (from ~1390 to 1700 AD) and with an instable water table (from ~1700 to 2012 AD). Fire activity has increased in the last millennium after constant human presence in the mire surroundings. Higher fire activity caused a rise in the water table, but later an abrupt drought appeared at the onset of the Little Ice Age. This dry phase is characterized by high ash contents and high charcoal-inferred fire activity. Fires preceded hydrological change and the response of TA to fire was indirect. Peatland drying and hydrological instability was connected with TA community changes from wet (dominance of *Archerella flavum*, *Hyalosphenia papilio*, *Amphitrema wrightianum*) to dry (dominance of *Cryptodiffugia oviformis*, *Euglypha rotunda*); however, no clear fire indicator species was found. Anthropogenic activities can increase peat fires and cause substantial hydrology changes. Our data suggest that increased human fire activity was one of the main factors that influenced peatland hydrology, though the mire response through hydrological changes towards drier conditions was delayed in relation to the surrounding vegetation changes.

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1. Introduction

Climate change and human activities strongly affect peatlands. In the northern hemisphere, *Sphagnum* peatlands cover extensive areas of northern Europe, Siberia and northern America (Joosten

and Clarke, 2002). These vulnerable ecosystems store one third of global terrestrial carbon (Freeman et al., 2004) and therefore, they are significant components of the global carbon cycle (Parish et al., 2008; Juutinen et al., 2013). However, it is still not well understood how these components may respond to ongoing global change. Climate change is expected to affect peatlands and their hydrological regimes (Vasander and Kettunen, 2006). The combination of low precipitation and high temperatures will increase fire frequency (Flannigan et al., 2013; Turetsky et al., 2015), particularly where ignition is far above the natural levels due to human activities (Conedera et al., 1996; Moreno, 2000). In consequence drought

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and burning will lead to lower carbon accumulation rates in mires and higher CO₂ releases to the atmosphere from peatlands (Kuhry, 1994; Pitkanen et al., 1999; Limpens et al., 2008). Therefore, it is important to monitor peatlands, as changing their carbon storage will have effects at a global scale.

Peatlands are important archives of the past environment, e.g. hydrological and vegetation changes, solar activity, fire frequency and carbon accumulation rates (Speranza et al., 2003; Charman et al., 2013; Loisel and Yu, 2013; Holmquist et al., 2014). Long temporal scales and the multi-proxy approach help in an understanding of how peatlands responded to climatic changes (Charman, 2010; Lamentowicz et al., 2013; Swindles et al., 2013) and anthropogenic disturbances (Olsson et al., 2010; Huntley et al., 2013; Turner et al., 2014; Fiałkiewicz-Kozieł et al., 2014a, 2014b). Looking at past long-term variability is a key to assess how peatlands may respond to global changes in the future (Seddon et al., 2014).

Polish peatlands located at the transition between oceanic and continental climate conditions are well investigated for past vegetation and hydrological changes (Tobolski, 1987; Herbichowa, 1997, 1998; Żurek et al., 2002; Tobolski, 2003; Lamentowicz et al., 2008, 2009, 2011; Gałka et al., 2013; Gałka et al., 2014), but only a few investigations of the long-term fire history and fire ecology are available (Lamentowicz et al., 2008, 2011; Gałka et al., 2014). For instance, it is still unknown how peatlands respond to the combined effects of heat waves, drought and fire. Fire history has not been analyzed in detail and reconstructions have mostly been used as background information for vegetation changes. To our knowledge, the first study comparing past hydrological changes revealed from testate amoebae with charcoal particles was published by Clifford and Booth (2013) and was devoted to three ombrotrophic peatlands in northern New England (USA).

In this study, we investigated long-term fire impact on a mire located in northern Poland. We selected Linje mire, because it is well studied in regard to its current functioning in relation to the microclimate and local hydrology (Hałas et al., 2008; Słowińska et al., 2010) and past vegetation cover (Kloss and Żurek, 2005; Noryśkiewicz, 2005). However, long-term hydrological dynamics and past fire activity have never been investigated. We reconstructed hydrological changes (using fossil testate amoebae and plant macrofossils) and past fire activity (using microscopic and macroscopic charcoal) over the last 2000 years to better understand the linkages between the fire regime and TA communities as well as TA inferred water table changes. This time interval covers documented periods of climatic and demographic changes, such as Migration Period, Medieval Warm Period and the Little Ice Age (Mauquoy et al., 2002; Büntgen et al., 2011), as well as the latest climate warming connected with rising human impact. The main aim of the investigation was to study the link between fire activity and peatland hydrological changes. Our working hypotheses were that: 1) fire activity in northern Poland had been intensified by human activity since the Medieval period, when the rise of the local population was recorded, and that 2) particular testate amoeba species responded to local peatland burning.

2. Study site

Linje mire is located in northern Poland, near the city of Bydgoszcz (Fig. 1). The peatland forms part of a protected area – the Linje mire nature reserve. The reserve covers an area of 12.70 ha, of which Linje mire accounts for 5.95 ha (53°11'15"–53°11'30" N, 18°18'37"–18°18'48" E) (Komendarczyk, 1992; Słowińska et al., 2010). Since 2008, the peatland has been listed in the Nature 2000 habitat area. The mire is located at 91 m a.s.l. under

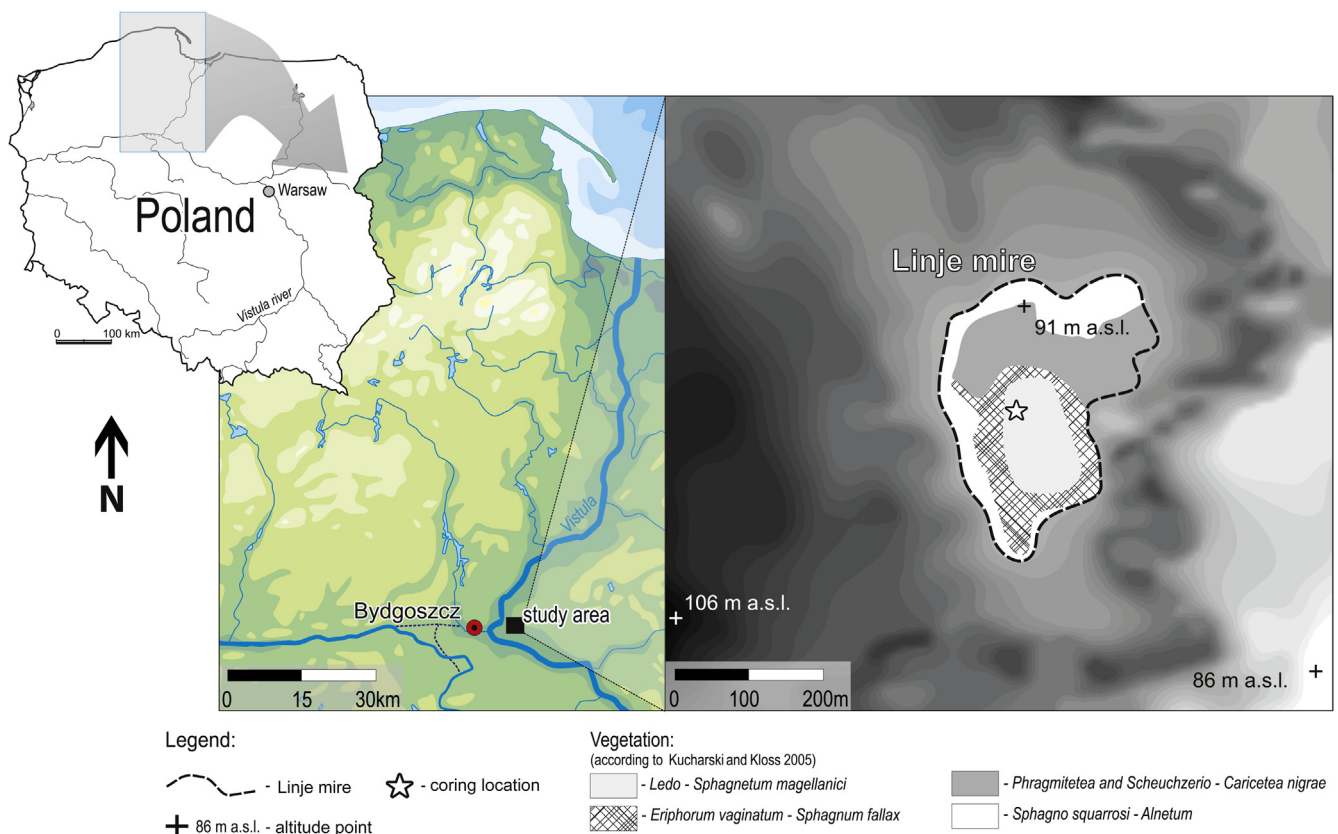


Fig. 1. Location of the study site – Linje mire.

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