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Environmental dynamics and carbon accumulation rate of a tropical peatland in Central Sumatra, Indonesia

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ABSTRACT

Tropical peatlands are important for the global carbon cycle as they store 18% of the total global peat carbon. As they are vulnerable to changes in temperature and precipitation, a rapidly changing environment endangers peatlands and their carbon storage potential. Understanding the mechanisms of peatland carbon accumulation from studying past developments may, therefore, help to assess the future role of tropical peatlands. Using a multi-proxy palaeoecological approach, a peat core taken from the Sungai Buluh peatland in Central Sumatra has been analyzed for its pollen and spore, macro charcoal and biogeochemical composition. The result suggests that peat and C accumulation rates were driven mainly by sea level change, river water level, climatic variability and anthropogenic activities. It is also suggested that peat C accumulation in Sungai Buluh is correlated to the abundance of *Freycinetia*, Myrtaceae, *Calophyllum*, Stemonuraceae, *Ficus* and Euphorbiaceae. Sungai Buluh has reasonable potential for being a future global tropical peat C sinks. However, considering the impact of rapid global climate change in addition to land-use change following rapid economic growth in Indonesia, such potential may be lost. Taking advantage of available palaeoecological records and advances made in Quaternary studies, some considerations for management practice such as identification of priority taxa and conservation sites are suggested.

1. Introduction

Peatlands play a major role in the global carbon cycle by storing around 600 Gt carbon or one third of the total global carbon pool (Gorham, 1991; Yu et al., 2011). Around 18% of the global peat carbon pool is stored in tropical regions, with around 65% stored in SE Asia (Page et al., 2011; Dargie et al., 2017). In SE Asia the largest share of tropical peat carbon is stored in Indonesia, with an estimated 57.4 Gt making up 65% of the total peat carbon in the tropics (Page et al., 2011). The estimation, however, cannot be precisely made due to limited information about the peat basal ages and the rates of carbon accumulation (Page et al., 2004; Dommain et al., 2011). SE Asian peatlands are distributed mainly in the river deltas and coastal plains of the islands of Sumatra and Borneo (Dommain et al., 2011; Veloo et al., 2014). Due to land use conversion and drainage following the economic growth of Indonesia, the existence of these peatlands is endangered (Miettinen et al., 2012).

Peatlands are sensitive to changes in precipitation and temperature, and are therefore vulnerable to global climate change (Page et al., 2011). A decrease in precipitation and an increase in temperature can lower the water table in peatlands, which in turn can increase the decomposition rate of the accumulated organic material (OM; Couwenberg et al., 2010). An experimental study in a peatland in Manitoba, Canada suggests that a temperature increase of 4 °C would cause a 40–80% loss of organic carbon due to water-table lowering (Ise et al., 2008). An approximate 30% decrease in annual mean C accumulation following a three years-long 60% precipitation reduction is reported from a study in Switzerland (Bragazza et al., 2016).

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Climate is, however, not the only factor controlling the rate of peat C accumulation (Charman et al., 2015; Dommain et al., 2015). For instance, an experimental study in Mer Bleue bog, Canada reported that the change in vegetation cover could lessen the C sink's capacity by altering the OM quality from slowly-decomposed *Sphagnum* to more decomposable vascular plants such as *Chamaedaphne calyculata* and *Ledum groenlandicum* (Juutinen et al., 2010). Yet, other factors besides climate such as water-table fluctuation and vegetation type are hardly discussed (Charman et al., 2015). Differently from northern peatlands where the relationship between climate, ecosystem dynamics and C accumulation is well studied, the information for tropical regions is sparse (Page et al., 1999; Yu et al., 2011). Consequently, the mechanisms driving peat C accumulation in tropical regions are still poorly understood, in particular in Indonesia with its extensive peatlands. Such knowledge is important for an improved understanding of past global carbon cycling as well as for an assessment of the future role of tropical peatlands in the rapidly changing environment (Page et al., 2004; Charman et al., 2013).

Supporting information such as palaeovegetational and palaeoenvironmental data which is required to identify the driving factors is also lacking (Birks, 2012; Dommain et al., 2015). For instance, a palaeoecological study in the Alaskan boreal forest found that fires occurred more frequently during wetter climatic conditions, contrary to the common assumption that fire is closely related to drought (Lynch et al., 2004). During the wetter conditions, the extensive grass growth increased fuel availability which than led to more frequent fire occurrence (Lynch et al., 2004).

In order to better understand the mechanisms of C accumulation in tropical peatlands, a multi-proxy palaeoecological study of a core from a peatland in the coastal area of Sumatra has been undertaken. These specific questions are addressed: 1. What factors control C accumulation in this peatland? 2. Is there any relationship between the rate of C accumulation and the composition of particular taxa? 3. How does the long-term (apparent) rate of C accumulation (LORCA) compare in the global context?

2. Study site

The Sungai Buluh peatland is situated 19 km from the coastline with an elevation ranging from 9 to 25 m above sea level (asl). The restoration area of Sungai Buluh (18,000 ha) is located in the Tanjung Jabung Regency, approximately 30 km north-east of the city of Jambi in Central Sumatra (Fig. 1a). The climate of the area is tropical humid, with yearly precipitation patterns mainly controlled by seasonal variation of the Asian-Australian monsoon and the Intertropical Convergence Zone (ITZC; Saji et al., 1999). Mean annual temperature is 26 °C with little variation throughout the year. Average annual rainfall is 2400 mm, with a slightly drier season corresponding to the onset of the southeast monsoon from June to September (Aldrian and Susanto, 2003; Karger et al., 2016). The inter-annual variability of rainfall is influenced by the El Niño–Southern Oscillation (ENSO; Aldrian and Susanto, 2003) and the Indian Ocean Dipole (IOD; Saji et al., 1999).

In general, the information on this protected peatland is sparse. The vegetation covering the restoration area is classified as secondary peat swamp forest (PSF; Melati et al., 2015). According to Tata et al. (2016) the original peat swamp forest cover was reduced by El Niño-related fires in 1997. Later in 2003, *Shorea pauciflora* and *Dyera polyphylla* were replanted in the Sungai Buluh area following instructions from the Department of Forestry of the Jambi Province (Nurjanah et al., 2013). The water table in this peatland fluctuated from 0.0 to 0.7 m (average 0.3 m) below the peat surface (http://space.geocities.jp/hkdkalimantan/jambi1/jambi1home.html). The area around the site is converted into agricultural field and plantations (Fig. 1b) such as oil palm (*Elaeis guineensis*) and pulp wood (*Acacia* spp.). The ancient Muara Jambi temple complex is found around 28 km south of the study area, on the banks of the Batang Hari River (Fig. 1a). The complex covers about 12 km^2 and it dates back to somewhere between the 9th and 14th centuries (Tjoa-Bonatz et al., 2009) and was supposedly the center of the Malayu Empire (Witrianto, 2014). This ancient kingdom in Sumatra is reported to have played a significant role in trading from the 10th to the 13th centuries as an overseas gateway for goods from the Sumatran hinterland, including forest and animal products (Witrianto, 2014). Such a significant role was lost after the conquest of the Majapahit Empire in the 14th century (Locher-Scholten, 2003).

3. Material and methods

In 2013, a 350 cm-long core (SB-B) was collected in the Sungai Buluh peat restoration area using a Russian Corer (Jowsey, 1966). The SB-B core (1°14′10″ S, 103°37′12″ E; 18 m asl) was photographed and described after recovery following the SE-Asian peat classification system (Esterle and Ferm, 1994; Wüst et al., 2003). Eight samples of the peat core and three additional samples from basal clay material were selected and sent to the AMS-laboratory at the University of Nürnberg/Erlangen, Germany and Poznan Radiocarbon Laboratory, Poland for radiocarbon dating (Table 1).

3.1. Palynological analysis

A palynological analysis was conducted to reconstruct past vegetation in the Sungai Buluh peatland. Samples for palynological analysis were taken at 10 cm intervals along the core. A total of 35 subsamples were processed following standard methods (Faegri and Iversen, 1989). Two tablets of *Lycopodium* spores were added as marker to each subsample prior to pollen extraction in order to calculate the pollen and spores concentrations. Pollen and spores were identified using the reference collection of pollen and spores of the Department of Palynology and Climate Dynamics, University of Göttingen, and other available literature (e.g. Anderson and Muller, 1975; Supiandi and Furukawa, 1986; Cole et al., 2015; Jones and Pearce, 2015; Pollen and Spore Image Database of the University of Goettingen – available at http://gdvh.uni-goettingen.de/). Counting of pollen and spore grains was conducted up to a sum of 300 pollen grains. Pollen and spore concentrations were calculated as grains cm^{-3}.

The pollen taxa were grouped into the categories of “mixed-riverine forest” (MRF), representing pollen produced by lowland and riverine plants; “peat swamp forest” (PSF), representing pollen of plants commonly found in peat swamp forest; “open vegetation” (OV), representing pollen produced by herbaceous plants; “ubiquitous” (UQ), representing pollen of plants which do not have a specific ecological distribution; and “mangrove” (MG) which represents pollen produced by salt tolerant plants (e.g. Soerianegara and Lemmens, 1994; Lemmens et al., 1995; Sosef et al., 1998; Padmanaba and Sheil, 2014; Cole et al., 2015). The pollen diagram was prepared with the program C2 (Juggins, 2007).

3.2. Stable carbon isotope and loss-on-ignition (LOI) analysis

Stable organic carbon isotope ($\delta^{13}C_{org}$) analysis was undertaken to trace the source of OM and change in environmental conditions (Khan et al., 2015). In total, 69 samples were taken along the SB core, dried at 60 °C for 48 h and finely ground. Samples were subsequently weighed (~1–1.5 mg) and treated with 1N HCl to remove carbonates prior to the analysis of organic carbon content (C_{org}). Determination of C_{org} was done using high temperature