Catena 139 (2016) 127–136

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Ground surface microtopography and vegetation patterns in a tropical peat swamp forest

Maija Lampela [a,*], Jyrki Jauhiainen [a], Iida Kämäri [a], Markku Koskinen [a], Topi Tanhuanpää [a], Annukka Valkeapää [b], Harri Vasander [a]

[a] Department of Forest Sciences, University of Helsinki, P.O. Box 27, 00014, Finland
[b] Department of Social Research, University of Helsinki, P.O. Box 54, 00014, Finland

ARTICLE INFO

Article history:
Received 27 February 2015
Received in revised form 17 December 2015
Accepted 28 December 2015
Available online 9 January 2016

Keywords:
Central Kalimantan
Water table
Tropical peatland
Mixed swamp forest
Surface elevation

ABSTRACT

In tropical peat swamp forests (PSF), the ground surface is covered with higher elevated surfaces, hummocks, and part of the year wet depressions, hollows. We present a detailed description of PSF floor microtopography combined with analysis of ground water table dynamics and the occurrence of vegetation in mixed swamp forest in Central Kalimantan, Indonesia. In the study area, hummocks and hollows were neither oriented in relation to the water flow nor did their spatial distribution seem to follow any other regularly repeated patterning. Combined data from long-term water table measurements and ground surface elevation mapping showed that for most of the year more than half of the soil surface is above the ground water table. The highest and lowest water table levels lasted a relatively short time with less fluctuation during higher than low water tables. Vegetation was concentrated on elevated surfaces such that tree seedlings were found at all elevations whereas mature trees were more abundant at higher elevations. We expect both flooding-induced oxygen deficiency in hollows and better nutrient availability in hummocks to steer the vegetation growth towards higher surfaces. The patterns of microtopography and vegetation between the areas closer to the margins versus the more central locations on the peat dome were similar.

1. Introduction

Ground surface microforms are common yet peculiar features in peatlands. In tropical peat swamp forests (PSF), the ground surface has higher elevated surfaces called hummocks and part of the year wet depressions called hollows. The difference between high and low surface levels can be several decimeters. Peat swamp forests are ombrotrophic dome-shaped peatlands in the wet tropics with several meters of deep peat formations at the dome center. Only a limited amount of detailed research exists concerning the ground surface microtopography of PSF. Earlier research has merely provided examples and overall descriptions of the forest floor structure (Anderson, 1983; MacKinnon et al., 1996; Brady, 1997; Shepherd et al., 1997; Yonebayashi et al., 1997; Page et al., 1999) or concentrated on species-specific interaction on the forest floor (Shimamura and Momose, 2005; Shimamura et al., 2006). Yet there is evidence that the conditions for decomposition, nutrient cycling and tree regeneration differ along the elevation gradient (Shimamura et al., 2006; Nishimua et al., 2007; Lampela et al., 2014), and soil respiration in hummocks and hollows differs in magnitude and diurnal patterns (Jauhiainen et al., 2005; Hirano et al., 2009).

In boreal and temperate peatlands, the hummocks and hollows in bogs or ridges and flarks in fens often form a distinct, organized, regularly repeated patterning perpendicular to the direction of water flow (typical spatial scale 10^1–10^2 m^2, Belyea and Clymo, 2001). Several theoretical approaches attempt to reveal the underlying processes responsible for this phenomenon. Traditionally, the theories explaining peatland microforms have been divided into three: (i) biotic, (ii) frost and ice action and (iii) gravity theories (Moore and Bellamy, 1974). More recently, peatland microforms have been linked to general ecological theories on spatial patterning (Rietkerk and Van de Koppel, 2008) with several approaches in mathematical modeling. Some approaches focus purely on hydrology such as the model developed by Swanson and Grigal (1988) and Couwenberg (2005) which is based on differences in hydraulic conductivity and uniform water flow along the slope. A model developed by Nungesser (2003) suggests that biotic processes such as different growth and decay rates between *Sphagnum* species are responsible for microform establishment. Eppinga et al. (2008) present a model where regular maze patterning in very flat peatland is not dependent on slope. Instead, the microforms are formed through a (i) positive feedback mechanism based on a higher rate of peat accumulation in hummocks and (ii) scale-dependent feedback mechanism

* Corresponding author.
E-mail addresses: maija.lampela@helsinki.fi (M. Lampela), jyrki.jauhiainen@helsinki.fi (J. Jauhiainen), iida.kamari@gmail.com (I. Kämäri), markku.koskinen@helsinki.fi (M. Koskinen), topi.tanhuanpaa@helsinki.fi (T. Tanhuanpää), annukka.valkeapaa@helsinki.fi (A. Valkeapää), harri.vasander@helsinki.fi (H. Vasander).

http://dx.doi.org/10.1016/j.catena.2015.12.016
0341-8162/

where there is a locally positive and longer distance negative connection between the nutrient accumulation and growth in hummocks driven by evapotranspiration. Both these processes together with differences in hydraulic conductivity may also result in perpendicular patterning in sloping areas. Several mechanisms may indeed coexist to explain processes in different geographical and morphological situations; Eppinga et al. (2009) suggested that differing combinations of biotic processes, hydrology, nutrient availability or peat accumulation may result in a similar surface patterning.

It is not clear if corresponding processes as the ones in boreal and temperate peatlands are responsible for the formation of microforms also in tropical peatlands. Based on the modeling approach for peatland microforms by Couwenberg (2005), Dommain et al. (2010) suggested that it is unlikely for such oriented microforms to establish in PSF due to the rather gentle slopes, wide annual water table fluctuations, and minor differences in peat hydraulic conductivity between hummocks and hollows.

Very little detailed information is available on the proportion of the forest floor in PSF that is occupied by hummocks and hollows, i.e., the amount of space underwater during wet periods. Published information includes descriptions of yearly and daily water table position dynamics without spatial coverage data (e.g., Takahashi et al., 2000; Shimamura and Momose, 2005; Shimamura et al., 2006; Wösten et al., 2008; Page et al., 2009), and estimations of the proportion of forest floor underwater at a certain time period (Jauhiainen et al., 2005; Hooijer, 2005) and that of hummocks and hollows covering the forest floor (50:50 in Page et al. (2009)). Lack of data combining water table levels with ground surface microtopography has led to arbitrary generalizations, e.g., "in undisturbed peat swamp forests the water level remains above the surface for most of the year (Dommain et al., 2010)".

The species-level occurrence of PSF trees in relation to ground surface elevation has been studied relatively little (Shimamura and Momose, 2005; Shimamura et al., 2006). A high water table combined with oxygen deficiency is generally expected to limit tree growth (Ridolfi et al., 2006). On the other hand, in PSF where vegetation is well adapted to recurrently wet and acidic soil, other factors such as nutrient availability (Lampela et al., 2014) may be important in steering tree growth in relation to ground surface elevation. Low water table levels over the long term may also lead to desiccation and higher mortality of tree seedlings (Nishimua et al., 2007).

In this study, we present a detailed description of PSF floor microtopography combined with analysis of ground water table dynamics and the occurrence of vegetation. Partly the same study sites were used in a previous article by Lampela et al. (2104) concentrating on the below-ground features (roots and peat properties) whereas here we concentrate on the above-ground phenomena. The study was implemented in a typical PSF type, mixed swamp forest, which is regionally widespread in Southeast Asia.

1.1. Hypotheses

1. Microtopographical differences (typical scale from 20 to 100 cm) in ground surface elevation occur more frequently in the direction from the center of the peat dome towards the river (along the elevation gradient) than in the perpendicular direction (along the river course) (Fig. 1). As in boreal and temperate peatlands, analogue biotic, hydrological, nutrient availability or peat accumulation-related processes described by Eppinga et al. (2009) also steer hummock formation in PSF.
2. Flat low-lying surfaces are more common than elevated ones. This difference in abundance is seen as positively skewed distribution of the elevation readings in the forest floor.
3. Seedlings are established at all elevations but long-term flooding during wet seasons causes higher seedling mortality at lower elevations while better nutrient availability favors growth in hummocks. Therefore, we expect to find seedlings at all elevations but saplings and trees prevailing at higher elevations. Typical water table level conditions thus limit tree growth at lower ground surface elevations.
4. Patterns in microtopography and vegetation within the studied forest type differ between the areas closer to the margins as opposed to the forest interior towards the center of the peat dome. Peat depth increases and the intensity of human-induced disturbance declines from the margins towards the forest interior. Both of these factors may affect microtopography and vegetation.

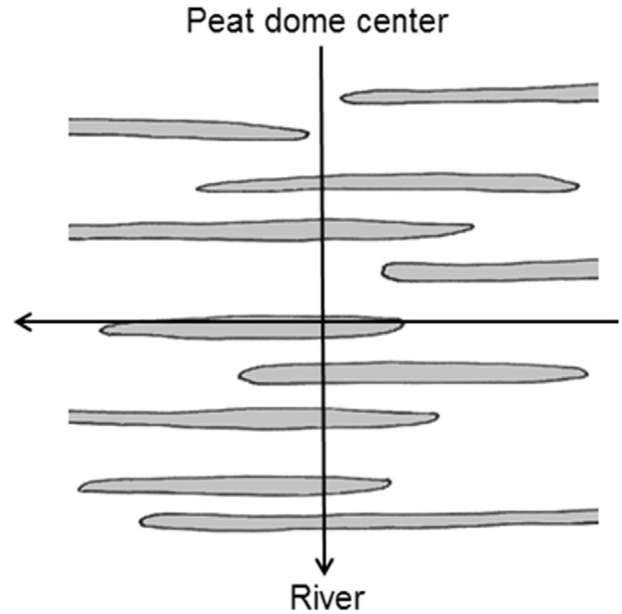

Fig. 1. Schematic illustration of the hypothesized orientation of hummocks and hollows in the forest floor. Hummocks are grey and hollows white. Vertical arrow shows the general direction of water flow from the center of the peat dome towards the margins crossing several hummocks. Horizontal arrow perpendicular to the direction of water flow crosses only one hummock within the same length indicating less elevation changes in this direction in comparison the first direction. Typical spatial scale for these formations is 10^1–10^2 m^2 in boreal peatlands (Belyea and Clymo, 2001).

2. Materials and methods

2.1. Site description

The study area is near Palangka Raya, Central Kalimantan, Indonesia, in the so-called Natural Laboratory field research area (Page et al., 1999) in the Sabangau forest (2°32′ S, 113°90′ E) (Fig. 2). The Natural Laboratory is situated 200 km inland from the Java Sea in very flat terrain with ground surface elevation at its peak 40 m.a.s.l. The climate is humid tropical with annual rainfall of approximately 2700 mm and a drier period lasting from May to October (Wösten et al., 2008).

The Natural Laboratory forest area is an ombrotrophic PSF that has been selectively logged in the 1970–90s. This can still be seen as a limited amount of big trees close to the forest edge. The forest type in the study area is a mixed swamp forest that comprised three canopy layers (Shepherd et al., 1997). The tallest trees reach 35 m, whereas the dominant canopy layer is from 15 to 25 m with a less dense storey at 7 to 12 m height (Shepherd et al., 1997). There are more than 150 tree species in the Sabangau forest with typical tree species such as *Calophyllum hosei*, *C. sclerophyllum*, *Palaquium leiocarpum*, *Shorea balangeran* and *Xylopia fusca* (Waldes and Page, 2002). The forest floor is characterized by pronounced microtopographical variation between hummocks and hollows. The peat depth in the Sabangau peat swamp forest varies from less than one meter near the river to 12.6 m in the middle of the peat dome (Shepherd et al., 1997), but at the exact locations of this study the peat depth ranged between 1.5 and 2.2 m (Lampela et al., 2014). The peat dome center with the ground elevation of 38 m.a.s.l.