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Promising native tree species for reforestation of degraded tropical peatlands

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ABSTRACT

Tropical peat swamp forests (PSF) of South East Asia are biodiversity hotspots and carbon-rich ecosystems under severe degradation and threat of extinction. Almost yearly recurring fires progressively devastate clear-cut PSFs. The need for both conservation and active restoration together with the appropriate information on the techniques and species is urgent. The aim of this study was to find native PSF species that are suitable for reforestation in the open degraded peatlands. We established two planting experiments in degraded peat areas with 21 tree species to study the survival and growth in relation to environmental factors for 2 years. The study sites were located in Central Kalimantan, Indonesia in the degraded peatland of the Ex-Mega Rice area and along the degraded margins of the river Sabangau. Seed material collected from local forests was grown in a field nursery and planted 6–11 months later in the field. Growth and mortality of the seedlings and environmental variables (water table, temperature) were monitored frequently for two years. The effects of the environmental variables on growth were tested with mixed-effects models and on mortality with Cox regression. As a result, we could derive species-specific information of the seedlings' early stage ecology and suitability for restoration. The most promising species based on the analysis were *Shorea balangeran*, *Adenanthera pavonina*, *Dacryodes rostrata* and *Lithocarpus dasystachys*. The comparison of the two differing areas revealed contrasting challenges: the main obstacle for reforestation in the Ex-Mega Rice area was fire, whereas in the river margin extreme water table fluctuation limited the success of the seedlings.

1. Introduction

Tropical peat swamp forests (PSF) are peculiar biodiversity hot spots and carbon-rich low-land ecosystems forming part of the Equatorial rain forests. With up to 20 m deep peat deposits, these forests are a substantial store of terrestrial carbon (Page et al., 2011a). Due to their remote locations and inaccessibility, the tropical peatlands of Africa and Amazonia have largely been discovered only recently (Lähteenoja et al., 2009; Lawson et al., 2015). In South East Asia, PSFs have been studied and utilized with increasing intensity already for several decades (Miettinen et al., 2016). More than two-thirds of the PSF cover of Peninsular Malaysia, Sumatra, and Borneo has been lost during the past 25 years to clear-cutting, drainage and conversion into oil palm and pulp plantations and agriculture. During the past two decades, the dry spells caused by the ENSO cycle in the Pacific have initiated several prolonged and intense seasons (years 1997–1998, 2002, 2006, 2009 and 2015) of widespread wildfires in the drained peatlands of South East Asia. In addition to drainage-induced peat decomposition causing carbon losses of c. 600 teragrams annually (Hooijer et al., 2010), fires on peatlands result in an additional c. 640 teragram CO_{2e} emission (GFED, 2014). Haze from the fires envelops extensive areas in SE Asia and damages people's health. In 2015, fire impacts were the most severe, consequently leading to political consensus in Indonesia to ban the future development of peatlands and endorse rewetting of the drained areas (Minister of Environment and Forestry, 2015).

Despite the expanding industrial use of drained and clear-cut PSFs, vast areas remain in a degraded state without any use (Miettinen et al., 2012). Environmental conditions in these mostly open peat areas, which lack the shelter and water retention typically provided by full canopy cover forest, are harsh for vegetation regeneration: (i) water table (WT) fluctuation is extreme in comparison to the intact PSF causing flooding during the wet season and excessive dryness in surface peat during the dry season; (ii)

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nutrients cycling between the living biomass and deposited litter (Lampela et al., 2014) have been removed together with the trees and leached from the ground that has been exposed to heavy rains (Könönen et al., 2015); (iii) temperatures are high in open areas (Hirano et al., 2015), with especially wide variation in the diurnal temperature when compared to forest (Jauhiainen et al., 2014). On top of that, high daytime temperatures inducing dryness in already low WT conditions in degraded areas increase the susceptibility to fires (Miettinen et al., 2012). Even though fire can be used to improve soil nutrient availability for plants and reduce soil acidity in agriculture, there is little benefit of the fires in the unmanaged degraded peat areas. The natural peat surface microtopography of the PSF, which creates opportunities for niche differentiation between tree species (Lampela et al., 2016), as well as most of the floral biodiversity is lost due to diminished tree cover, drainage and fires. Wild fires that interrupt natural regeneration and penetrate the peat layer also most certainly destroy both the soil seed bank (Page et al., 2009) and the mycorrhizas that are important associates to several tree species. On the other hand, according to Blackham et al. (2014), the seed rain of PSF tree species mostly through wind and bird dispersal is sufficient for forest regeneration even in the several times burnt, severely degraded areas. The species diversity in the seed rain is anyhow low (Blackham et al., 2013), seed predation by rodents may substantially reduce the amount of seeds available (Blackham and Corlett, 2015), and without active restoration the process of natural reforestation would be very slow. Therefore, we believe that active restoration measures should be considered in order to abate the expanding degradation, conserve biodiversity and carbon, and fight the haze problem caused by the recurring fires.

It is widely accepted (see Clewell and Aronson, 2013 and the references therein) that to reforest degraded ecosystems, the main focus should be on the native species. Fortunately, the prerequisites for native species regeneration may be favorable in degraded tropical peat. Contrary to the commonly observed pattern of invasive and exotic pioneer species colonizing degraded areas, the seed rain as well as the established seedlings in the degraded PSF areas consists almost entirely of the native PSF species (Blackham et al., 2013, 2014). In addition, the commercial species not native to peat soils, such as oil palm and acacias, rarely succeed on peat without WT regulation and heavy fertilization (Page et al., 2011b; Jauhiainen et al., 2012). From other peatland ecosystems we know that the adaptation of the peatland specialized species to the wet environment is remarkable; for example, boreal peat vegetation shows adaptations to such conditions as pH < 4, severe nutrient and oxygen deficiency, soft growing substrate and changing water table conditions (Sjörs, 1950; Økland et al., 2001; Rydin and Jeglum, 2013). There is much less research on the specific adaptations of plant species to demanding conditions in the PSF. Still, similar features, such as extensive tree root formations (plank and stilt roots) showing adaptation to soft growing media and gas transport to and from the submerged roots via pneumatophores can be found in the PSF. A recent study (Pangala et al., 2013) has also shown that some PSF tree species can emit methane through their stems to discharge the potentially poisonous gas from the tissues. We may assume that some of these adaptations will also be beneficial in the reforestation of degraded PSF.

The overall knowledge on the environmental condition requirements of the PSF tree species is scarce and there are still several unidentified species and unresolved taxa within the PSF flora (Anderson, 1972; Page et al., 1999; Miyamoto et al., 2003; Van Eijk and Leenman, 2004; Shimamura et al., 2006; Turjaman et al., 2006, 2011; Giesen, 2009; Mirmanto, 2010; Graham et al., 2013). The majority of the knowledge on the PSF tree species can only be found in technical reports by governmental bodies and NGOs, while local traditional knowledge of the species focuses on certain timber, fruit or other forest product trees (Jewitt et al., 2014; Giesen, 2015). In the present conditions, there is a need for more specific information on tree ecology applicable for the use of nature conservation and ecosystem restoration in tropical peatlands.

The aim of this study is to find native PSF species that are suitable for reforestation in the very demanding conditions of the degraded, open and fire-affected, peatland areas. To do so, we established a planting experiment in degraded peat areas. We did not perform any hydrological restoration, site preparation or fertilization. Instead, we studied the potential of the tree species to survive and grow in such conditions that are most likely present in practical reforestation projects that have very limited resources for individual seedling maintenance. We expected the main factors affecting the performance of a seedling to be related to the WT position, climatic factors and seedling size at planting.

2. Methods

This study was conducted in the province of Central Kalimantan in Indonesia at two sites on both sides of the river Sabangau near the capital Palangka Raya: 1. 'Kalampangan site' in the former Mega Rice Project (MRP) area block-C near the village Kalampangan on clear-felled, drained and several times burnt, former peat swamp forest, and 2. 'Natural laboratory site' on the degraded edge of natural peat swamp forest in Sabangau National Park in the so-called Natural laboratory area (googlemaps link, Appendix B). The mean annual precipitation and air temperature from 2002 to 2010 measured near the sites of this study in the degraded peatland area (northern part of block C of the MRP) were 2450 (±596, SD) mm yr^{-1} and 26.2 (SD ± 0.3) °C, respectively (Hirano et al., 2014). The local climate has a drier season starting commonly in July and ending at latest in November, but the interannual variation in the duration of the wet and dry seasons and the amount of precipitation is large.

2.1. Kalampangan experiments

We established three blocks on locations with differing WT conditions: Kalampangan dry (2°19′32″S 114°00′59″E), middle (2°19′18″S 114°01′05″E) and wet (2°20′24″S 114°02′11″E). The peat depth in the locations is approximately 4 m. The vegetation and its structure in the blocks are typical for the repeatedly burnt degraded peat in the area (Fig. 1). It consists mostly of ferns (*Pteridium aquilinum* (L.) Kuhn, *Stenochlaena palustris* (Burm. f.) Bedd., *Polypodium* sp.), some bushes (*Melastoma malabathricum* L., *Ploiarium alternifolium* (Vahl) Melch., *Ficus deltoidea* Jack), and sparse small trees (*Combretocarpus rotundatus* (Miq.) Danser, *Cratoxylum glaucum* Korth., *Cratoxylum arborescens* (Vahl) Blume, *Acacia crassicarpa* Benth.). The overall floral biodiversity is low (we counted less than 30 plant species in all the three blocks) in comparison to the intact PSF, and other than the occasionally dense growth of ferns, the vegetation is sparse with bare peat patches largely present. In comparison to the natural PSF microtopography (Lampela et al., 2016), the soil surface is very flat with compacted surface peat and sparse depressions caused by peat fires. 90% of all ground surface elevation variation lies within 32 cm amplitude, based on the leveling data from the three blocks. Of the three blocks, the dry block had most frequent burnt depressions, nearly never visible WT, least vegetation and was mostly dominated by *Pteridium*, the middle block had very flat soil surface with ferns and sparse bushes whereas the wet block had occasionally thick bush vegetation and most of the year water-filled depressions.

According to the previous studies from the same location (Kalampangan block middle), the mean values for pH, bulk density, carbon, nitrogen, C:N ratio, phosphorus and potassium, calcium