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Effect of riparian management on stream morphometry and water quality in oil palm plantations in Borneo

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ABSTRACT

Large-scale conversion of tropical forests into agricultural plantations, particularly oil palm (OP) across South East Asia exerts enormous pressure on freshwater systems. To mitigate impacts on aquatic ecosystems, the retention of riparian buffer zones along stream banks are often advocated for freshwater management. However, there is a severe lack in ecological information available on tropical stream systems advising on the efficacy of different riparian buffer types (with varying quality) to mitigate stream physico-chemical properties after conversion for agricultural use. To test the hypothesis that greater riparian disturbance will have negative effects on stream geomorphology and water quality, we assessed the impacts of riparian vegetation structure and density on stream chemical and physical properties in different riparian buffer types commonly used in OP plantations subjected to a gradient of disturbance: (i) Native forest (NF); (ii) OP – forested buffer (OPF); (iii) OP – untreated palms buffer (no fertilizer and pesticide application) (OPOP); and (iv) OP – treated palms (OPNB). Across the disturbance gradient, riparian species diversity and density decreased with taller trees and high foliage cover. Foliage cover heavily influenced the amount of light received at the stream, bank and buffer zone that concur with stream water temperatures. In-stream litter substrate decreased with increased riparian disturbance. OP streams had higher phosphorus and potassium concentrations that can be attributed to the use of fertilizers while sodium concentrations were higher in NF streams. Generally, OPF was most similar to NF sites whereas OPOP and OPNB sites had similar characteristics showing that riparian vegetation type influences the physical and chemical characteristics of streams. Thus, the use of high quality riparian buffers with forested riparian vegetation in OP plantations to reduce the impacts of land conversion on streams is supported.

1. Introduction

Southeast Asia is undergoing rapid and extensive conversion of natural forests into exotic monocultures, particularly oil palm (OP) (*Elaeis guineensis* Jacq. family Arecaceae) (Koh et al., 2011; Wilcove and Koh, 2010). OP is a prevalent tropical crop posing the largest immediate threat to tropical forests (Gunarso et al., 2013) as it is the most rapidly expanding crop, particularly in tropical Asia and West Africa (Phalan et al., 2013; Pirker et al., 2016). Malaysia and Indonesia supply about 84% of global oil palm production (FAO, 2014) with large expansions expected in other tropical systems like West Africa and Neotropics (Butler and Laurance, 2009; Vargas et al., 2015). Converting self-generating and highly complex tropical forests into monoculture OP plantations has adverse impacts on stream environmental conditions as changes in the surrounding riparian vegetation heavily influence productivity and functioning of aquatic ecosystems (Boothroyd et al., 2004). Riparian trees help regulate aquatic ecosystem processes through inputs of organic matter and nutrients, decreased light incidence, changes in habitat and energy supply (i.e. volume and velocity of flow entering the system), stabilising channels and filtering sediment and contaminant loads washed into streams (Casotti et al., 2015; Costa et al., 2012).

The development of OP plantations notably changes riparian vegetation diversity and structure as forests rich in biodiversity are replaced by single species plantations cultivated with an even age class and uniform planting density (Fitzherbert et al., 2008) with possible alterations to stream physical characteristics (e.g. organic matter input, canopy cover). There are also morphological changes to streambed and bank dynamics with wider stream channel (Davies-Colley, 1997) with greater bank erosion levels (Quinn et al., 1997) reported in plantation streams compared to pristine forested streams. Few studies have reported degradation in OP stream water quality with increased nutrients and toxins attributable to anthropogenic inputs of fertilizer, pesticide, herbicide, liming and discharge of palm oil mill effluent into streams. (Carlson et al., 2014; Lord and Clay, 2006; Mercer et al., 2014). In addition, there are also reports of increased soil erosion and

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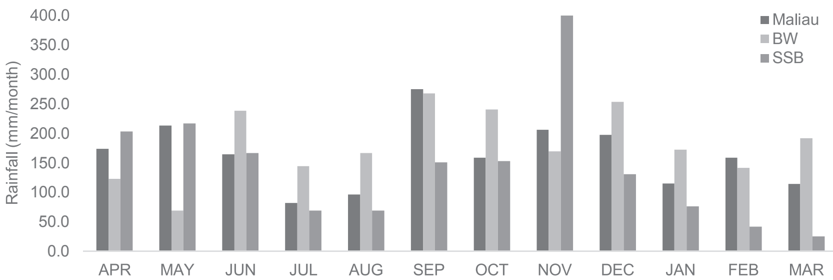

Fig. 1. Total monthly rainfall in Maliau (NF), Benta Wawasan (OPF/OPNB) and Sabah Softwoods (OPOP) from April 15'–March 16'. *Outlier in SSB (Nov) = 805.5 mm/mo.

sedimentation due to logging and reduced vegetation cover in oil palm plantations (Hartemink, 2005; Mercer et al., 2014).

To reduce the impacts of land conversion on aquatic ecosystems, the retention of vegetated riparian buffer zones (strips of vegetation left intact along stream and riverbanks) are often encouraged to protect and maintain water quality (Alemu et al., 2017; Boothroyd et al., 2004). However, previous studies reveal inconsistent results that complicates the understanding of the effectiveness of riparian buffer types (de Fernandes et al., 2014; de Souza et al., 2013; Encalada et al., 2010; Heartsill-Scalley and Aide, 2003; Langer et al., 2008; Mori et al., 2015) as different stream frameworks react differently to similar management approaches (Belsky et al., 1999). With most of these studies focused on temperate streams and other agricultural systems (e.g. eucalyptus, pine, etc.), more emphasis on tropical stream systems is needed, particularly as tropical regions have different environmental conditions (e.g. temperature and rainfall) and flora and fauna (Ewers et al., 2011). Currently, despite the rapid conversion rates of tropical forests into OP plantations, there has been little published research on the efficacy of different riparian buffer types in OP plantations to reduce stream disturbance with respect to stream morphometry, incidence of light, in-stream litter substrate and water quality (Luke et al., 2017). As a result, insufficient ecological data is available to appraise existing policies and legislation guidelines on riparian zone management in the tropics (Ewers et al., 2011). There is a crucial need to address this research gap by evaluating the functional significance of riparian buffers of different types in oil palm plantations as suitable water management approaches in tropical regions, particularly within OP plantations (Dislich et al., 2016).

Thus, the aim of this study was to evaluate the impacts of riparian buffer types with differing riparian vegetation structure and complexity (varying quality) on stream physical and chemical characteristics when intact native forests are converted into oil palm plantations in Sabah, Borneo. Understanding how riparian buffer types can influence stream physicochemical characteristics is a major priority for management and conservation as the potential loss of biodiversity is outpacing our ability to understand its implications (Boyero et al., 2009). Riparian buffer types commonly used in OP plantations were assessed and follows a disturbance gradient. We hypothesized that: (i) Plantation streams lacking a buffer would have lowest riparian vegetation quality with reduced vegetation density and most simplified structure (ii) Across the disturbance gradient, canopy cover decreases with increases in light incidence at bank, buffer and stream levels as well as stream temperatures (iii) Riparian vegetation density and complexity influences total mass and diversity of in-stream litter substrate; (iv) Plantation streams will have higher nutrient concentrations compared to natural forested sites (v) Stream physical characteristics (e.g. bankfull channel width and depth, flow rate, bank erosion) is higher in more degraded streams. With this, moderators could then be identified and useful mitigation measures for sustainable land use change from tropical forests to OP plantations can be suggested.

2. Materials and methods

2.1. Study area and experimental sites

This survey was conducted within an industrial OP area in plantations managed by Sabah Softwoods Berhad (SSB) and Benta Wawasan (BW) and a pristine forest, Maliau Basin Conservation Area (MBCA), a Class I forest reserve (with the entire catchments of natural forest) in Tawau, Sabah on East Borneo. Tawau was formerly covered in native forest, dominated by Dipterocarpaceae species with heavy logging since the early 1960s. Majority of logged areas have been replanted with OP since the 1980s with current plantations totalling 1.36 million ha (Wahid, 2010). Planting of OP typically involves clear cutting of native tropical forests (> 100 years old) right up to stream bank however some plantation companies choose to retain a buffer zone that can vary in width from 3 to 30 m alongside OP plantation streams. These buffers can consist of native forest remnants, replanted fast growing or selected native species with discontinued usage of herbicide to allow natural succession of vegetation. The climate of Tawau is equatorial, typically hot and wet throughout the year (Fig. 1) with heavy and frequent rainfall and little seasonality. On average, monthly rainfall measurements were similar in all sites throughout the year (April 15'–March 16') with rainfall averaging 174.5 mm/mo in Maliau, 182.0 mm/mo in BW and 175.9 mm/mo in SSB. However, rainfall values did differ from month to month between sites. In SSB, highest rainfall occurred in Nov at 805.5 mm/mo and rainfall ranged from 25.8–203 mm/mo in the other months. In Maliau and BW, highest rainfall fell in Sept at 275.4 mm/mo and 268 mm/mo respectively. There were some irregularities in rainfall between Jul and Aug with tendencies of more heavily disturbed stream sites in the OP plantations to undergo distressed flow regimes (personal observation). This study was conducted between Nov 15'–Feb 16' when rainfall pattern was more consistent. OP sites were studied first (within SSB, then BW) and subsequently the natural forest.

Three replicate headwater streams (1st–3rd order) were chosen within the four forest and riparian buffer types (Fig. 2): (i) Native forest reference sites (NF); (ii) OP plantation streams with riparian zones dominated by native vegetation with taller native trees extracted during logging about 5–10 years ago (OPF in BW); (iii) OP plantation streams with a riparian zone of untreated palms (no application of herbicide, pesticide and fertilizer) and a native vegetation understorey (OPOP in SSB); and (iv) OP plantation streams clear cut to stream edge with treated oil palms (application of herbicide, pesticide and fertilizer) (OPNB in BW). To accurately describe the effects of OP plantations on streams, only naturally occurring streams originating from forested areas reserved for water catchments within and beside the plantations were chosen. In OP plantations, three stream sites that were similar in terms of age, extent of plantation, agricultural treatments and environmental conditions were chosen to account for local variations and act as replicates (Table S1). The corresponding natural forested stream sites that act as reference sites are in Maliau Basin Conservation Area (MBCA) which is the closest Class I forest reserve to SSB. This ensured effective comparison as the plantation area of SSB substituted forest structures similar to those found in MBCA.