Ecological Indicators 95 (2018) 53–62

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Riparian buffers mitigate impacts of oil palm plantations on aquatic macroinvertebrate community structure in tropical streams of Borneo

Darshanaa Chellaiah[a,*], Catherine M. Yule[a,b]

[a] Monash University Malaysia, Jalan Lagoon Selatan, Bandar Sunway, 47500 Petaling Jaya, Selangor, Malaysia
[b] University of the Sunshine Coast, Sippy Downs, Queensland, Australia

ARTICLE INFO

Keywords:
Aquatic invertebrates
Water quality
Biomonitoring
Tropical streams
Land-use
Riparian buffer
Oil palm plantation
Macroinvertebrate
Freshwater
Bioindicator

ABSTRACT

Southeast Asia is undergoing extensive conversion to oil palm (*Elaeis guineensis*) monocultures with fast growth expected in West Africa and South America. Despite rapid conversion rates, few tropical studies evaluate land-use change impacts on stream communities, with even fewer studies examining oil palm plantations (OP). In this pioneer study we compare macroinvertebrate community assemblages and their relationships with physico-chemical properties in OP streams bordered by different riparian buffer types to streams in a lowland dipterocarp forest in Sabah, Malaysian Borneo. Our study sites were in increasing levels of riparian disturbance (reduced vegetation density, diversity and structural complexity): (i) Native reference forested sites (NF); (ii) OP streams buffered with patches of natural forest (OPF); (iii) OP streams buffered with untreated oil palm (no chemical application at buffer sites; OPOP); and (iv) OP streams without buffer (OPNB). Macroinvertebrates were collected from leaf litter bags deployed with leaves of varying quality - native *Macaranga tanarius* and exotic oil palm, and retrieved after 14 days. We found that although invertebrates are typically influenced by resource quality, no differences were detected in their assemblages between the leaf species. All litter bags were dominated by collector-gatherers, with few shredding invertebrates, indicating that they were using the leaves as a habitat rather than a food source. We found no significant differences in macroinvertebrate abundance, richness and sensitive taxa richness (EPT) regardless of the rate of riparian disturbance. However, PERMANOVA showed significant differences between the macroinvertebrate community composition of heavily disturbed OPNB and pristine NF streams. Retaining high quality riparian buffers in OPF streams and lower quality understory in OPOP streams posed intermediate effects on macroinvertebrate community composition. The differences between sites were explained by the increase in nutrients, particularly potassium and phosphorus, stream water temperatures and erosion levels that negatively correlated with macroinvertebrate assemblages in oil palm streams. These findings support the use of riparian buffers in oil palm plantations to mitigate land conversion impacts on macroinvertebrate communities in tropical streams.

1. Introduction

Benthic macroinvertebrates play crucial roles in many stream ecological processes. They are involved in nutrient cycling by decomposing organic matter (Vanni, 2002) and also help regulate energy flow through aquatic food webs by linking basal resources (e.g. algae and detritus) with upper trophic levels (e.g. fish, shrimp) and microbial communities (Ramírez and Gutiérrez-Fonseca, 2014; Villanueva et al., 2012). With tropical forests being extensively cleared for agricultural expansion, freshwater macroinvertebrates are severely affected by changes in stream environmental conditions as most of these conversions occur throughout lowlands and hills in catchments previously drained by forested streams (Jinggut et al., 2012; Lorion and Kennedy, 2009; Masese et al., 2014a). Existing tropical studies have shown negative impacts following forest conversion, reporting a shift in macroinvertebrate community structure in disturbed stream sites (see Bertaso et al., 2015; Suga and Tanaka, 2013; Jinggut et al., 2012). Also reporting a reduction in overall taxon richness with loss of sensitive taxa and increase in relatively tolerant taxa in streams subjected to agricultural land-use and anthropogenic stresses (see Lorion and Kennedy, 2009; Al-Shami et al., 2011; Hepp et al., 2016).

Changes in macroinvertebrate assemblages in anthropogenically impacted sites are attributable to degradation in riparian zones and stream conditions that influences macroinvertebrate distribution and occurrences. For example, in disturbed streams, alterations in organic matter detrital inputs affect benthic food sources while changes to

* Corresponding author.
E-mail addresses: dche57@student.monash.edu, darshanaamc@gmail.com (D. Chellaiah), catherine.yule@monash.edu, cyule@usc.edu.au (C.M. Yule).

https://doi.org/10.1016/j.ecolind.2018.07.025
Received 3 July 2017; Received in revised form 11 July 2018; Accepted 13 July 2018

stream bank and bed dynamics influences habitat availability to macroinvertebrate consumers (Suga and Tanaka, 2013). In addition, increased sedimentation in streams can blanket benthic food substrates (i.e. aquatic algae and leaf litter) as well as smother gills and filter-feeding devices of several macroinvertebrate taxa (Mercer et al., 2014). Also, nutrient pollution due to agrochemical inputs, including pesticides can directly cause macroinvertebrate mortality (Mercer et al., 2014; Fierro et al., 2016). However, different species have varying tolerances to pollution and physical disturbance (Morse et al., 2007; Uherek and Pinto Gouveia, 2014), as such responses of these biological communities to environmental degradation provides a useful measure of overall water quality. Consequently, protocols using macroinvertebrates (e.g. biological diversity or biotic indices) as structural indicators of stream health have been widely applied (Mahazar et al., 2013; Chang et al., 2014; Buss et al., 2014; Uherek and Pinto Gouveia, 2014).

To manage impacts of agricultural conversion on stream biota, a method typically suggested is retaining native riparian buffers along stream and river banks (Naiman et al., 1993). Studies have found that the use of native riparian vegetation helps regulate organic matter and nutrient inputs, decreases light incidence, stabilizes channels, and filters sediments and contaminants (Casotti et al., 2015; Guevara et al., 2015; de Souza et al., 2013; de F. Fernandes et al., 2014) thus ameliorating the impacts of agriculture on aquatic macroinvertebrates. For example, a study by Quinn et al. (2004) found that native forested riparian buffers support comparable stream invertebrate communities to native forests while clear-cut streams negatively impacted macroinvertebrates, eliminating several sensitive taxa.

In Southeast Asia, South America and West Africa, oil palm (OP) plantations are the principal drivers of tropical deforestation (Gunarso et al., 2013; Vijay et al., 2016) and typically supports fewer species compared to other tree crops (Luiza-Andrade et al., 2017; Cunha et al., 2015; Almeida et al., 2016; Lees et al., 2015). In Borneo, several studies have reported the loss of taxonomic diversity when tropical forests are converted into oil palm plantations, however most of these studies focus on terrestrial invertebrates/anthropod/amphibians (e.g. butterflies, birds, anurans, ants) (Sheldon et al., 2010; Gillespie et al., 2012; Turner and Foster, 2009; Wang and Foster, 2015; Luke et al., 2014; Senior et al., 2013) with little emphasis on aquatic macroinvertebrates in this region. Mercer et al. (2014) found lower invertebrate abundance, species richness and diversity in oil palm plantations compared to rainforest streams in Sarawak Borneo, however there are no studies to our knowledge focusing on the efficacy of riparian buffers to mitigate these plantation impacts on aquatic macroinvertebrates in Borneo. The limited tropical studies show variation from slight to severe impacts when assessing the effects of riparian quality on macroinvertebrate communities (Hepp et al., 2016; Suga and Tanaka, 2013; Lorion and Kennedy, 2009) but most of these studies are from other tropical regions (e.g. Brazil, Puerto Rico) with different agricultural systems. Since the type and density of riparian vegetation is crucial to provide suitable environments for the establishment and colonization of benthic macroinvertebrates (Oliveira et al., 2014), it is important to conduct plantation-specific studies to understand and evaluate the different riparian management techniques within oil palm plantations. With Borneo having few species described and countless endemic species of stream macroinvertebrates uncatalogued (Jacobsen et al., 2008), the loss of biodiversity is outpacing our ability to understand it's impacts on overall stream ecosystem functioning.

The objectives of this study were to assess changes to aquatic macroinvertebrate communities between streams in a tropical forest and streams following conversion to oil palm plantations, and to compare the efficacy of different riparian buffer types (native vegetation, untreated oil palm, no buffer) on mitigating oil palm plantation impacts on aquatic macroinvertebrate communities in tropical streams. This is the first study in this region to investigate the impact of different types of riparian buffers on macroinvertebrate communities in oil palm plantations. We compared benthic invertebrate taxa, community structure and several structural metrics of invertebrate community integrity in 12 streams within the Tawau Industrial area in Sabah, Borneo obtained from litter bags containing senescent leaves of native (*Macaranga tanarius* (L.) Müll. Arg., Euphorbiaceae) and oil palm (*Elaeis guineensis* Jacq. Arecaceae) tree species. We hypothesized that with increasing disturbance: (1) macroinvertebrate community composition differs with decreased taxa richness, and pollution-sensitive taxa, particularly Ephemeroptera, Trichoptera, and Plecoptera (EPT) and (2) leaf quality influences macroinvertebrate community composition with higher invertebrate abundance in leaf litter bags with higher quality leaves (*Macaranga tanarius*).

2. Materials and methods

2.1. Study sites

This study was conducted from Nov 2015 to Feb 2016 in Tawau, Sabah in East Borneo, a region formerly covered in lowland tropical forests dominated by Dipterocarpacae species. Tawau, known as the "land of the farmers" due to large scale agricultural expansion has about 1.36 million ha of OP plantations established on undulating land 60–350 m above sea level. The study area consisted of water catchments managed under the Yayasan Sabah foundation with a reference site, Maliau Basin Conservation Area (MBCA), a Class I forest reserve and OP plantations managed by Sabah Softwoods Berhad (SSB) and Benta Wawasan Sdn Bhd (BW). Four forest and riparian zone types were selected across a disturbance gradient from natural forested streams, through OP streams with native forested buffer, to OP streams with native understorey buffer and OP streams without a buffer (Table 1, Fig. 1 and Fig. S1):

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ecolind.2018.07.025.

A total of 12 streams were selected, three within each of the four forest and riparian buffer types (n = 3) (Table 1 and Fig. 1) that were categorised based on riparian structure (i.e. riparian diversity, height structure, density of vegetation and anthropogenic treatment in the buffer area) (see Chellaiah and Yule, 2018 for detailed information). Replicate plantation streams chosen were similar in size, morphological features, age and extent of plantations. Plantation streams all originated

Table 1
Description of study sites.

Forest and riparian type	Abbr	Site	Coordinates	Elevation
Mature native forest reference sites	NF	Maliau Basin Conservation Area	N04°44′24.7″ E116°57′53.1″	176m
Oil palm (OP) plantations with riparian zones dominated by native vegetation with taller native trees extracted during logging about 5–10 years ago	OPF	Benta Wawasan Sdn Bhd	N 04° 37′34.6″ E117° 38′18.3″	218m
OP plantations clear cut to stream edge but with a riparian zone of untreated oil palms (no application of herbicide and fertilizer) and an understorey of native vegetation	OPOP	Sabah Softwoods Berhad	N04°36′27.0″ E117°43′49.7″	199m
OP plantations clear-cut to stream edge, with application of herbicide and fertilizer to stream edge	OPNB	Benta Wawasan Sdn Bhd	N 04° 37′53.3″ E117° 35′18.5″	139m