Biological Conservation 222 (2018) 164–171

Contents lists available at ScienceDirect

Biological Conservation

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

Land-use change is associated with a significant loss of freshwater fish species and functional richness in Sabah, Malaysia

Clare L. Wilkinson[a,b,c,*], Darren C.J. Yeo[b], Tan Heok Hui[c], Arman Hadi Fikri[d], Robert M. Ewers[a]

[a] Department of Life Sciences, Imperial College London, Silwood Park, Silwood Park, Buckhurst Road, Ascot, Berkshire, SL5 7PY, UK
[b] Department of Biological Sciences, National University of Singapore, 14 Science Drive 4, Singapore 117543, Republic of Singapore
[c] Lee Kong Chian Natural History Museum, National University of Singapore, 2 Conservatory Drive, Singapore 117377, Republic of Singapore
[d] Institute of Tropical Biology & Conservation, Universiti Malaysia Sabah, Malaysia

ARTICLE INFO

Keywords:
Deforestation
Freshwater fish
Land-use change
Oil-palm
Southeast Asia

ABSTRACT

Global biodiversity is being lost due to extensive anthropogenic land cover change. In Southeast Asia, biodiversity-rich forests are being extensively logged and converted to oil-palm monocultures. The impacts of this land-use change on freshwater ecosystems, and particularly on freshwater biodiversity, remain largely understudied and poorly understood. We assessed the differences between fish communities in headwater stream catchments across an established land-use gradient in Sabah, Malaysia (protected forest areas, twice-logged forest, salvage-logged forest, oil-palm plantations with riparian reserves, and oil-palm plantations without riparian reserves). Stream fishes were sampled using an electrofisher, a cast net and a tray net in 100 m long transects in 23 streams in 2017. Local species richness and functional richness were both significantly reduced with any land-use change from protected forest areas, but further increases in land-use intensity had no subsequent impacts on fish biomass, functional evenness, and functional divergence. Any form of logging or land-use change had a clear and negative impact on fish communities, but the magnitude of that effect was not influenced by logging severity or time since logging on any fish community metric, suggesting that just two rounds of selective impact (i.e., logging) appeared sufficient to cause negative effects on freshwater ecosystems. It is therefore essential to continue protecting primary forested areas to maintain freshwater diversity, as well as to explore strategies to protect freshwater ecosystems during logging, deforestation, and conversion to plantation monocultures that are expected to continue across Southeast Asia.

1. Introduction

Anthropogenic land cover change through agricultural expansion and intensification is currently a major driver of global biodiversity loss (MEA, 2005; Phalan et al., 2013). The destruction of tropical forests is of particular significance owing to the disproportionately high levels of biodiversity present in the tropics (Bradshaw et al., 2009; Laurance et al., 2012), marked declines in biodiversity when tropical forest is converted to other land-use types (Phalan et al., 2013), and the unabated levels of deforestation due to increasing human demands for food, timber and other products (Sodhi et al., 2004; Wilcove et al., 2013). Large areas of logged forest and agriculture will be key features of future tropical landscapes. Primary forests are critically important for conserving tropical biodiversity (Gibson et al., 2011) and once-logged forests in Southeast Asia have high conservation value for terrestrial taxa (Edwards et al., 2014), but focussing on these habitats alone is not sufficient. The impacts of this large scale land-use change and other anthropogenic activities on freshwater ecosystems and biodiversity in tropical streams remains largely understudied and poorly understood (Ramirez et al., 2008). It is important to understand how these changing landscapes impact upon aquatic as well as terrestrial biodiversity, and to devise strategies that provide protection mechanisms.

The most widespread and destructive threat to aquatic ecosystems is habitat modification that results from converting natural areas to agricultural land (Allan and Flecker, 1993; Laurance et al., 2014). Extensive logging and deforestation across the tropics (Achard et al., 2002; Hansen et al., 2010) has caused large scale modifications to catchments, resulting in changes in water quantity, quality, de-regulation in stream hydraulics and increased sedimentation levels (Inoue and Nunokawa, 2005; Iwata et al., 2003). The effects of deforestation on the species richness of fish are variable. Species richness can be increased (Lorion and Kennedy, 2009), decreased (Brook et al., 2003; Toham and Teugels, 1999), or unaffected (Bojsen and Barriga, 2002) by tropical deforestation, with equally variable impacts on fish community

* Corresponding author at: Imperial College London, Silwood Park, Buckhurst Road, Ascot, Berkshire, SL5 7PY, UK.
E-mail address: clare.wilkinson12@imperial.ac.uk (C.L. Wilkinson).

https://doi.org/10.1016/j.biocon.2018.04.004
Received 27 November 2017; Received in revised form 22 March 2018; Accepted 2 April 2018
0006-3207/

composition (Bojsen and Barriga, 2002; Giam et al., 2015).

In Borneo, freshwater fish community composition is thought to be structured more strongly by local, mesohabitat structures (pool, riffle, or run) than larger, catchment scale processes such as logging history, although time since logging activity was shown to positively affect the abundance of common cyprinids (Martin-Smith, 1998a, 1998b). In comparison, Iwata et al. (2003) showed different fish guilds or community metrics responded differently to deforestation. For example, the abundance of benthic fish and other taxa was lower in deforested catchments, which was attributed to increases in sedimentation, but nektonic (free-swimming) fish did not suffer reductions. It is suggested that deforestation or habitat alteration can affect fish communities by changing the taxonomic identities and functional diversity of communities, whereas mesohabitat differences affect the functional composition of communities (Casatti et al., 2012), causing reductions in functionally distinct species (Villéger et al., 2010).

Land-use change causes alterations in sediment load, nutrient runoff (e.g., from fertilisers), canopy cover and thus temperature, leaf litter and woody debris, to name but a few environmental variables (Luke et al., 2017). All of these impacts change the microhabitats that fish inhabit and can affect taxonomic or functional groups differently (e.g., Jones et al., 1999; Newcombe and Macdonald, 1991; Sazima et al., 2006). Moreover, more destructive logging practices can have a bigger impact. The practice of slash and burn agriculture led to long term degradation of streams because of its greater impact on vegetation and soil conditions than selective logging regimes (Iwata et al., 2003). The impacts of conversion of forest to oil-palm culture, however, can be mitigated by the retention of forest patches and riparian reserves. Aquatic diversity was maintained at pre-conversion species richness and functional diversity within oil-palm monocultures in the Indo-Malay region when riparian reserves were present (Giam et al., 2015). By contrast, stream sites within plantations lacking riparian reserves exhibited an average 42% reduction in aquatic species diversity (Giam et al., 2015). Despite this, there is considerable variation in the impacts of land-use change on freshwater ecosystems, leading to renewed calls to better understand the potential interactions of land-use change with other stressors specific to certain regions such as dams, drought or invasive species (Macedo et al., 2013; Taniwaki et al., 2017). Thus regional studies are needed to uncover local impacts of varying land-use on freshwater fish communities in order to determine and validate protection mechanisms to safeguard freshwater ecosystems in the long term.

The aim of this study was to determine how freshwater fish communities change in headwater stream catchments that vary over an established land-use gradient from protected forest areas, twice-logged forest, and oil-palm plantations with and without riparian buffers, in Sabah, Borneo. This is among the first studies in Southeast Asia comparing freshwater fish diversity across this suite of land-uses, and in such a close geographical space. We expected to see a decline in fish species richness (following the 42% decline previously reported by Giam et al., 2015), biomass, and all metrics of functional diversity, as forest is logged or converted to oil-palm plantations and in comparison to protected forest catchments (Giam et al., 2015; Iwata et al., 2003; Juen et al., 2016; Martin-Smith, 1998a, 1998b, 1998c; Mercer et al., 2014; Pye et al., 2017). Community composition is expected to change in disturbed habitats (Iwata et al., 2003; Kwik and Yeo, 2015), reducing to a subset of species present in protected forests. In addition, oil-palm streams with a forested riparian buffer (~30 m wide on both sides of the stream) were expected to have a higher richness, biomass and functional diversity than those without riparian buffers (Giam et al., 2015; Lorion and Kennedy, 2009). We predicted this would be due to changes in canopy cover over the streams impacting, for example, water temperature, litter fall and litter retention within the stream. With ongoing deforestation and conversion to oil-palm plantations in Southeast Asia, it is crucial to understand how these processes impact freshwater biodiversity in order to develop strategies to protect freshwater ecosystems and maintain the ecosystem services they provide.

2. Methods

2.1. Study site

Study sites were located on small, headwater streams (3–10 m wide, ≤1.2 m maximum depth) in southeastern Sabah, Malaysian Borneo (117.5°N, 4.6°E). The landscape is a mosaic of protected forest (PF) areas consisting of primary lowland dipterocarp rainforest (Danum Valley Conservation Area and the Brantian Tatulit Virgin Jungle Reserve; catchment above ground biomass (AGB) average 350 T Ha^{-1}), twice-logged forest (LF2; AGB average 122 T Ha^{-1}) and salvage-logged forest (LF3; AGB average 95 T Ha^{-1}), and oil-palm plantations with (OPB) and without riparian reserves (OP; planted between 1998 and 2011; AGB average for all oil-palm streams is 38 T Ha^{-1}) (Pfeifer et al., 2016). The sites form part of the Stability of Altered Forest Ecosystems (SAFE) Project (Ewers et al., 2011). The landscape is drained by tributaries of the Brantian, Kalabakan and Segama rivers, all of which empty into the Celebes Sea.

We collected data from 23 headwater stream catchments, where possible matched to the SAFE project experimental streams (length ~2 km; catchment area ~260 ha; slope ~16°; (Ewers et al., 2011)). Five catchments were in protected areas (four at Danum Valley Conservation Area, and one in the Brantian Tatulit Virgin Jungle Reserve; Fig. 1). Three catchments were in continuous twice-logged forest (selectively logged in the 1970s and again in the 1990s–2000s) and six in recently salvage-logged forest in the SAFE project experimental area (selectively logged in the 1970's and 1990s–2000s, and salvage-logged between 2013 and 2015). Another five catchments were in oil-palm plantations with riparian reserves of approximately 30 m width, and four oil-palm catchments without riparian reserves. Oil-palm catchments had palms that varied in time since planting from 4 to 11 years. Each catchment was an independent tributary, ensuring spatial independence of data. Within each catchment, a 100 m transect was established.

2.2. Fish sampling

Field work was conducted between February–July 2017. We sampled fishes on clear-weather days using three capture methods, performed in the following order at each transect: (1) three pass electrofishing (model EFGI 650; Bretschneider Spezialelektronic), (2) cast netting (2.75 m diameter net with 1 cm mesh), and (3) tray (push) netting (dimensions 60 × 45 cm, 2 mm mesh). Tray (push) netting involves capturing fish by placing a rectangular steel-framed net downstream of possible habitat (undercut banks, leaf litter and rocky areas) while disturbing the habitat, e.g., by kicking. In each transect, before sampling began, we placed stop nets (2 mm mesh) at upstream and downstream boundaries to prevent immigration and emigration of fish during our sampling period. We employed these methods to target all major fish microhabitats so as to obtain comprehensive and unbiased descriptions of fish communities (Giam et al., 2015; Kennard et al., 2006).

Captured fishes were identified to species (Inger and Chin, 2002; Kottelat, 2011), measured, uncommon species (< 30 individuals previously weighed; 9% of individuals) were weighed using a portable balance, and most (85%) were returned to the stream at the point of capture. Prior to this study, 5136 fish had been weighed and measured at these stream transects for other studies (CW, unpub. data), so for common species we recorded their length only and used length-mass regressions to estimate weight (Appendix 2–1). A subset of fish (up to three individuals of each species from each stream) were preserved as vouchers for proof of identification. These fish specimens were euthanized with MS-222, fixed in 10% formalin, and transferred to 75% ethanol for storage in the Lee Kong Chian Natural History Museum, National University of Singapore. Fish capture, handling and