



Stream ecosystem integrity is impaired by logging and shifting agriculture in a global megadiversity center (Sarawak, Borneo)

Tajang Jinggut^a, Catherine M. Yule^{a,*}, Luz Boyero^{b,c}

^a School of Science, Monash University, Jalan Lagoon Selatan, Bandar Sunway, 46150, Selangor, Malaysia

^b Wetland Ecology Department, Doñana Biological Station-CSIC, Avda Americo Vespucio s/n, E-41092, Sevilla, Spain

^c School of Marine and Tropical Biology, James Cook University, Townsville, Qld 4811, Australia

HIGHLIGHTS

- ▶ We compare ecosystem integrity of pristine vs. logged vs. farmed streams in Borneo.
- ▶ We use both functional (leaf breakdown) and structural indicators (associated fauna).
- ▶ Both practices alter ecosystem integrity, but the impacts of logging are more severe.
- ▶ Mechanized logging affects both the structure and function of stream ecosystems.
- ▶ Slash and burn clearing for shifting agriculture affects structure more than function.

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ABSTRACT

In common with most of Borneo, the Bakun region of Sarawak is currently subject to heavy deforestation mainly due to logging and, to a lesser extent, traditional slash-and-burn farming practices. This has the potential to affect stream ecosystems, which are integrators of environmental change in the surrounding terrestrial landscape. This study evaluated the effects of both types of deforestation by using functional and structural indicators (leaf litter decomposition rates and associated detritivores or 'shredders', respectively) to compare a fundamental ecosystem process, leaf litter decomposition, within logged, farmed and pristine streams. Slash-and-burn agricultural practices increased the overall rate of decomposition despite a decrease in shredder species richness (but not shredder abundance) due to increased microbial decomposition. In contrast, decomposition by microbes and invertebrates was slowed down in the logged streams, where shredders were less abundant and less species rich. This study suggests that shredder communities are less affected by traditional agricultural farming practices, while modern mechanized deforestation has an adverse effect on both shredder communities and leaf breakdown.

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1. Introduction

Streams are sentinels and integrators of environmental change in the surrounding landscape, so by examining their condition we obtain critical information on the ecological consequences of anthropogenic activities (Williamson et al., 2008). A useful approach for the investigation of stream condition is assessing ecosystem integrity (= ecological integrity) using both structural and functional indicators, which offer complementary information (Gessner and Chauvet, 2002). While structural indicators of stream condition (e.g., biological diversity or biotic indices) have been used extensively (Rosenberg and Resh, 1993), the use of functional indicators is relatively novel (Gessner and Chauvet, 2002). Certain ecological processes such as leaf litter decomposition have proved useful as

functional indicators, mostly in temperate and boreal regions of the planet (e.g. Hladyz et al., 2010; McKie and Malmqvist, 2009).

Here we used structural and functional indicators of ecosystem integrity in conjunction to assess the condition of streams flowing through degraded areas in Borneo. Although this island is one of the few megadiversity centers of the world, and holds a highly endemic flora and fauna (over 15,000 species of flowering plants, 3000 species of trees and 640 species of vertebrates) (MacKinnon et al., 1998), it also has one of the highest rates of deforestation on the planet. In the Malaysian state of Sarawak, over 50% of the original forest area has been destroyed in the past 50 years and more than 300,000 ha disappear annually (King, 1993).

Until recently most of the island was forested, and the indigenous inhabitants (the Dayaks and Orang Ulu) traditionally relied on slash-and-burn agriculture to cultivate hill rice (dry land rice) and other minor crops. Evidence of major forest clearing in Borneo, indicating shifting agriculture, dates back over 2500 years (Maloney, 1985) and

* Corresponding author. Tel.: +60 3 5514 6104; fax: +60 3 5514 6099.

E-mail address: catherine.yule@monash.edu (C.M. Yule).

even today it is still widely practiced. Originally clearing the forests (areas of about 1 ha at a time) with stone tools and fire, farmers now use chainsaws followed by fire to leave a carpet of nutrient rich ash for planting crops. The soil is not plowed, rather seeds and cuttings are planted using dibble sticks, resulting in minimal disturbance and erosion, and there is no use of fertilizers, pesticides or irrigation. Fields are abandoned after about three years, but the fallow cycle varies depending on population pressures and the availability of land, so growing populations are resulting in decreasing fallow periods. Increasingly shifting agriculture is becoming less common as logging is destroying the forests where it was previously practiced, and permanent crops are predominating (Bruun et al., 2009; Hansen, 2005).

Between 2000 and 2010, a total of 1.8 million hectares were estimated to have been deforested, representing a 10.7% decline in the total forested area of East Malaysia (Miettinen et al., 2011). Today, deforestation in Borneo is mainly due to mechanized logging, increasingly preceding conversion to oil palm plantations, but much of the deforested land is simply abandoned following logging (Curran et al., 2004). Logging and agricultural conversion to oil palms in Sarawak are undertaken as a result of government policies (Hansen, 2005). Between 2005 and 2007, 1.89% of the forest was cleared, and this increased to 2.14% from 2009 to 2010, a rate 3.5 times that of all of Asia (SarVision, 2011), due to both legal and illegal logging.

We predicted that (1) both slash-and-burn farming and logging would impair the ecological condition of streams, and (2) the consequences of logging would be more marked than those of farming because of its more destructive nature. We tested these hypotheses by examining the characteristics of shredder assemblages (as a structural indicator) and the rates of leaf litter decomposition (as a functional indicator) in streams subject to farming and logging compared to pristine streams in Sarawak. The shredders are a group of detritivores that feed on leaf litter and thus are key decomposition agents in streams (Hieber and Gessner, 2002) and a crucial link between the terrestrial and aquatic food webs (Wallace et al., 1997). We chose decomposition as a functional indicator because most headwater streams are heterotrophic systems, fueled by in-stream processing of terrestrial detrital inputs (Wallace et al., 1997), and because the effectiveness of this process as an indicator of ecological integrity has already been demonstrated (Young et al., 2008).

2. Material and methods

2.1. Study area

The study was conducted in the Bakun region of Sarawak, Borneo (Fig. 1). The climate is humid tropical with high temperatures (22–33 °C), heavy rainfall (4070 mm per annum) and high humidity

(35–88%) all year round, although rains are more intense in November–December and March–April (Department of Irrigation, Sarawak). The study sites were located within the Sungai Asap resettlement scheme, 50 km from the Bakun Hydroelectric Power Dam, which includes pristine areas and areas subject to both farming and logging. Our study sites were one 50-m reach in each of two pristine stream sites (Sg. Belian and Sg. Rusan), two ‘farmed’ sites (Sg. Lavek and Sg. Lit) and two ‘logged’ sites (Sg. Makabun and Sg. Kecil) (Fig. 1). The farmed and logged sites were sampled immediately downstream of the disturbance. It was not possible to sample the farmed sites *in situ* because the streams were completely covered by fallen trees and debris preventing access. The sites were all lowland (134–282 m asl) with similar characteristics in terms of original riparian vegetation (lowland dipterocarp forest), channel morphology (alternating riffles and pools) and substrate (dominated by cobbles and gravel). Clearing for shifting agriculture and mechanized logging both result in destruction of the riparian vegetation (no buffer zones are retained in either practice in the region), thus leaves entering the streams are not freshly abscised, instead they are from the debris created by tree felling. Whereas mechanized logging results in extensive substrate disturbance and massive inputs of sediment into the streams, sedimentation following clearing for agriculture is relatively minor.

2.2. Shredder assemblages

In August 2008 we collected ten leaf litter samples from each site. Although shredders are often more common in pools (Cheshire et al., 2005), they are generally abundant in riffles of Malaysian streams because leaf litter tends to accumulate against cobbles and boulders, particularly during elevated flows that accompany the regular high rainfall events (Yule et al., 2009). For this reason, we collected five samples from each habitat type. Sampling consisted of collecting a 20×20 cm area of leaf litter from the substrate using a 250 µm-mesh dip net. Invertebrates were carefully separated from the litter and preserved in 70% ethanol. Invertebrates were sorted under a stereo microscope and identified to the lowest possible taxonomic level using available taxonomic keys (Yule and Yong, 2004).

In the laboratory, we examined invertebrate gut contents to identify shredders (whose gut contents were mainly composed of leaf and wood fragments > 1 mm). Gut contents were removed under 40× magnification onto a glass slide before being mounted with polyvinyl alcohol–lactophenol. Using a compound microscope we estimated the % of plant tissue in the guts (which was nearly 100% in all specimens that were classified as shredders). Only shredders were considered for further analyses because (1) shredders break down the leaf litter and thus they are structural indicators of stream conditions

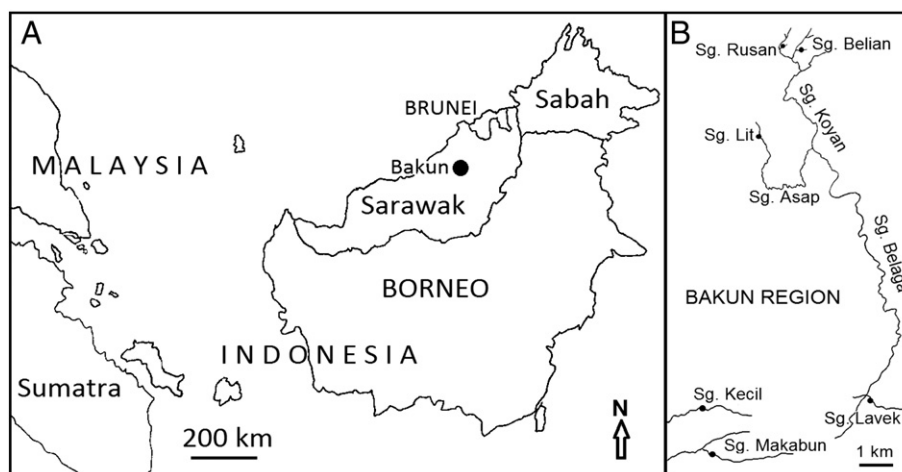


Fig. 1. A. Map of the Malaysian region. B. Location of the study sites in the Bakun Region, Sarawak.

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