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Biodiversity patterns of aquatic macroinvertebrates in tropical forests streams as a response to logging activities and deforestation

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ABSTRACT

The biodiversity of aquatic macroinvertebrates in virgin (VJR) and logged over forest (LO) streams in Perak Integrated Timber Concession (PITC), Temenggor Forest Reserve, Perak, Malaysia was investigated. A total of 2048 individuals from VJR streams were collected (40.2 individual/m^2) compared to 1392 individuals (19.9/m^2) recorded from streams in the logged forests (LO). Alpha and gamma diversity measures of the VJR streams were higher compared to LO streams. The beta diversity index value in the VJR (2.21) streams was higher compared to the LO streams (1.17). The correlation between similarity matrices (Sorensen' distance coefficient) of macroinvertebrates data sets from VJR and LO streams was significant ($r = 0.836$, $P < 0.05$). The species indicator analysis identified few significant indicator species for the VJR streams such as *Ctenipocoris* sp. (Naucoridae), *Cryptoperla* sp. (Peltoperlidae) and *Diplectrona* sp. (Hydropsychidae). In conclusion, the VJR streams of Temenggor Forest Reserve supported relatively diverse aquatic macroinvertebrates. The logging activities and deforestation in the investigated areas were determinant factors justifying the reduction in macroinvertebrates abundance and loss of biodiversity in the forest streams.

1. Introduction

Forest ecosystem in the tropics accommodates at least two-thirds of the earth's terrestrial biodiversity and provides significant local, regional and global human benefits through the provision of economic goods and ecosystem services [32]. The International Tropical Timber Organization (ITTO) reported that very few tropical forests are managed on a sustainable basis [62]. For example, deforestation in the 1990s is estimated at 14.6 million hectares per year [48]. Tropical forests are a key component of the global carbon cycle and contribute >30% of terrestrial carbon stocks and net primary production [14,66,67,81]. Tropical forests including those in South East (SE) Asia become a spot of interest for global biodiversity [4–6,13,41,44,68,72] and loss of these habitats may increase global extinction rates [14,19,22,61,66–68,71,83] and on the ability of these forests to provide essential ecosystem sources to humans [44,81]. Therefore, proper sustainable forest management is extremely urgent before an immeasurable amount of resources will be lost [13,69].

Streams of tropical forests differ from temperate streams in many aspects, such as evolutionary history, water temperature, diversity of riparian vegetation [6,28,36] and aquatic biota [24,25]. Although recent information about the biodiversity in Asian streams does not reflect the true state of biodiversity [5,6,36,60,63], the Asian natural inland aquatic ecosystems are diverse in their ecological patterns [26,28,36] and in particular riverine systems are highly rich in their biota [24,25]. Unfortunately, the faunal biodiversity of SE Asian aquatic ecosystems especially those in tropical forests is increasingly threatened by numerous factors such as deforestation, agricultural land use and road construction [2,4,5,13,16,21,26,36,58,60,67,71,82]. Despite this, freshwater macroinvertebrates including those from tropical areas are infrequently included in the conservation plans [10,11,26,28,64].

In tropical Asian region, several natural aquatic ecosystems have undergone modifications, degradation and loss of species due to different human activities [23,38,71]. Aquatic habitats are being impacted and eradicated by urbanization and deforestation [2,16,26,28,38]. Deforestation rates in SE Asian forests are at higher than in other tropical areas [56] changing the runoff patterns and increasing siltation of the rivers [24,25,27]. Although research in tropical SE Asian streams has increased over the last two decades (see [4–6,16–18,34,60,63]), there is still a gap

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in the knowledge of fauna and ecological understanding of the tropical streams compared with that of temperate streams [4–6,16,24,26,28,58,72].

There are several studies highlighting the adverse effects of anthropogenic forest disturbance on SE Asian biotas [2,14,45,50–52,67,69]. However, quantitative studies at large scale of the impacts of forest disturbance and deforestation on tropical biodiversity are scarce [30,60,66]. Parts of Malaysian forests had been logged as early as in the 1950s. Subsequently, freshwater ecosystems in the tropical forest of Malaysia are affected following the changing in the canopy cover and degradation of the ecosystem [6,16,59]. Although deterioration of the biodiversity issue has emerged as an important alert globally, the threats to macroinvertebrate diversity in Malaysian tropical forest streams are scarcely studied [22,24]. The present study aimed to investigate the diversity patterns of macroinvertebrates in tropical forest streams on the influence of timber logging on the biodiversity patterns. It was hypothesized that pristine streams in the virgin forests would have high diversity of aquatic invertebrates compared to streams in the logged over forests.

2. Materials and methods

2.1. Study site

The Perak Integrated Timber Complex (PITC) concession is a 9000 ha virgin forest located at 5° 24′ 40″ to 5° 34′ 15″N latitude and 101° 33 0 to 101° 39′ 30″ E longitude in the state of Perak, in the northern part of Malaysia Peninsula (Fig. 1). It is part of 148,870 ha Temenggor Forest Reserve, within the Hulu Perak District in Perak state that was gazetted as permanent forest estate under the Malaysian National Forestry Act 1984. It lies on the western side of the Titiwangsa Main Range with rolling hills, long slopes and many narrow ridge tops between 400 m to about 1000 m above sea level (asl). Located in a virgin Hill Dipterocarp Forest, the PITC forest is rich with meranti bukit (*Shorea platyclados* Sloot. ex Foxw), keruing (*Dipterocarpus costulatus* Slooten), mersawa (*Anisoptera* sp.), kempas (*Koompassia malaccensis* Benth) and merbau (*Intsia palembanica* Miq.). The forest is described as having a typical tropical monsoon climate with high temperatures (from 24.2 °C to 29.9 °C) and high humidity (from 70% to 98%). High rainfall is experienced in April and October each year reaching 3000 mm per year at times. Months of low rainfall are February and July [46].

The PITC is a state-owned company under the Perak State Economic Development Corporation. It has been given rights to manage a forest concession area using the Selection Management System that allowed for a more flexible harvesting regime with the need to safeguard the environment. The forest was divided into 30 compartments. Compartment 1–3 were logged from 2001 to 2006 while compartment 4 was undergoing logging in 2007 and the rest of the compartments would be logged in phases until 2030.

In this study, the logged over forest was located in compartment 1 that was logged in 2001 while the virgin forest was in compartment 5. No logging activity or any other human disturbance has been reported previously from the virgin forest area (Fig. 1). Streams in both logged over forest (LO) and virgin jungle reserve (VJR) were investigated during the rainy season of 2007–2008.

To ensure the similarity of habitat characteristics, the habitat score for was calculated based on the composite scores of habitat assessments following the method of Barbour et al. [8]. Four criteria of the stream were measured and compared among stations; substrate particle size, substrate embeddedness; current speed and canopy cover. Environmental parameters such as stream characterization, watershed features, riparian vegetation, in-stream features, presence of large woody debris, aquatic vegetation, water quality, substrate types were recorded. Percentage of habitat types in the area sampled and other conditions that would help describe the sampling areas like high flows, treacherous rocks, difficult access to stream were noted as this information would indicate adverse sampling conditions.

2.2. Sampling of macroinvertebrates

Macroinvertebrates were sampled using a D-frame dip net of 0.3 m diameter and 0.3 m high with 300 μm-mesh net (as recommended by [35]). At each sampling site the macroinvertebrates were sampled along approximately 100 m reach from riffle, pool, run, leaf pack, stream margins with vegetation and woody debris within the 100 m reach of the stream. Different types of habitat were sampled in approximate proportion to their representation of surface area of the total macroinvertebrate habitat in the reach. Habitat types contributing <5% of the stable habitat in the stream reach was not sampled. Collection of samples began at the downstream end of the reach and proceeded upstream. The D-pond aquatic net was placed on the river substratum with its mouth facing upstream and an area approximately a square meter in front of the net, was disturbed by legs (kick-technique of Merrit and Cummins 1994) for about 2 min. Small boulders, cobbles and pebbles were rubbed by hand to dislodge macroinvertebrates clinging on their surfaces into the net. At stream margins, the net was dragged for 3 m over marginal vegetation. Collected samples were washed through a plastic sieve and placed into labeled polyethylene bags. Benthic samples required to yield a representative estimate of macroinvertebrate populations were estimated using the index of precision [31] based on a preliminary collection following which 10 samples were collected from each stream.

All samples were transported to the laboratory in a Coolman® ice chest. In the laboratory, each sample was then washed under tap water through a sieve (300 μm pore) and transferred into a white plastic pan filled with sufficient amount of water. The collected benthic samples were sorted and preserved in 80% ethanol. The macroinvertebrates specimens were identified using keys of Morse et al. [57] and Yule and Yong [82] under the microscope to the lowest taxonomic level possible.

2.3. Physicochemical parameters of the forest streams

At each stream in each forest, measurements of physicochemical parameters such as water depth, river width, water pH, water temperature, and Dissolved Oxygen (DO) were made *in situ* at three randomly selected locations. Dissolved Oxygen and temperature were measured with a YSI-57 m (YSI Inc., Yellow Springs, Ohio) and measurement of water pH was taken using a Termo-Orion Model 210 pH meter. The depth and width of the river were measured using a metal measuring tape. To analyze selected chemical parameters (BOD, COD, ammonium-N and TSS), three replicate of water samples were randomly collected using 500-ml plastic bottles. Each bottle was appropriately labeled and thoroughly rinsed out with the stream water immediately prior to collecting a sample. Samples were transported to the laboratory under cool conditions and stored at 4 °C for further processing. The Total Suspended Solids (TSS) were estimated using the method of Tomar [76]. The Ammonium-N contents of the water were measured at appropriate wavelength using the YSI 9100 photometer test kit.

2.4. Data analysis

To describe the biodiversity patterns of the macroinvertebrate in virgin and logged over forest streams, alpha, beta and gamma diversity were calculated following Whittaker [80] and Heino et al. [40,41]. Alpha diversity is expressed as mean species richness in the two types of streams, and gamma diversity was simply the total number of species detected in the 7 virgin or 7 logged over forest streams. Species Diversity and Richness software (version 4.1.2) [65] was used to calculate beta diversity for both stream types.

The multiple-site similarity measure has been calculated based on presence/absence data. Similarity of macroinvertebrate communities