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The effects of reduced-impact logging practices on soil animal communities in the Deramakot Forest Reserve in Borneo

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ABSTRACT

The effectiveness of reduced-impact logging practices on the maintenance of biodiversity in Borneo has been recognized for some organisms (e.g., mammals). We investigated the effects of reduced-impact logging and conventional selective logging practices on biodiversity by using soil fauna as indicators of disturbance. The study sites were the production forests of the Deramakot Forest Reserve and the Tangkulap Forest Reserve in Sabah, Malaysian Borneo (5°14–30′ N, 117°11–36′ E). We compared macro- and mesofauna in a pristine forest with no logging, a reduced-impact logged forest in Deramakot Forest Reserve, and a conventionally logged forest in Tangkulap Forest Reserve.

The mean density of soil macrofauna (excluding ants) did not differ significantly among the three forest categories (nested ANOVA, $p > 0.05$). This tendency was also seen in the density and species richness of Oribatida and Collembola, which showed little difference among forest categories. Nonmetrical multidimensional scaling (NMS) ordination diagrams revealed a different community composition in conventionally logged forest sites compared with the other sites. The scores for the NMS first or second axis of soil fauna were correlated with one or more of the values for density, diversity, and species composition of trees. A RELATE test showed the congruence between trees and the Collembola and Oribatida community composition between sites. The results implied that the soil fauna community composition was related to tree communities. In conclusion, the impacts of logging on decomposers in the soil animal communities have been mitigated by the introduction of reduced-impact logging in Deramakot Forest Reserve through the protection of tree vegetation. It is important to consider monitoring the influence of selective logging on soil fauna with regard to the dynamics of the species (or group) composition because total density and species (or group) richness of soil fauna displayed only a marginal response to the different logging practices.

1. Introduction

Natural tropical production forests require a synergy between the production of wood and the conservation of biodiversity. One possible way of meeting both demands is to introduce improved management techniques such as reduced-impact logging (RIL). Recently, sustainable forest management (SFM) combined with RIL and forest certification has been adopted in some production forests in Sabah, Malaysian Borneo (Kleine and Heuveldop, 1993; Lagan et al., 2007). RIL includes careful pre-harvest planning and improved harvesting techniques (Putz et al., 2008) but also involves reduced harvest and post-harvest silvicultural treatments (Kleine and Heuveldop, 1993; Lagan et al., 2007). The effectiveness of RIL in maintaining biodiversity has been recognized for selected organisms (Seino et al., 2006; Mannan et al., 2008; Imai et al., 2009). However, this needs to be further substantiated in other taxa because the benefits of RIL can be specific to certain taxonomic groups.

Less-mobile soil macro- or mesofauna are more useful than mobile species for evaluating the effects of localized logging impacts on biota. Because the reduction of soil damage is often a

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major emphasis of RIL (Putz et al., 2008), monitoring soil-related biodiversity may be a practical way of testing the validity of RIL for protecting soil conditions. Studies of the response of soil fauna to selective logging in the tropics have been limited to a few taxa of soil macrofauna (e.g., earthworms: Camilo and Zou, 2001, termites: Lima et al., 2000, ants: Widodo et al., 2004). Litter-dwelling ants are known to be indicators of logging disturbance in tropical forests (e.g., Belshaw and Bolton, 1993; Roth et al., 1994; Vasconcelos, 1999; Vasconcelos et al., 2000; Brühl, 2001). However, there are still only a few studies of the response of other soil macrofauna and mesofauna to selective logging (Hassall et al., 2006).

Our aim was to investigate the effects of RIL and conventional selective logging on biodiversity by using soil fauna as indicators of disturbance. Selective logging may affect soil fauna in two ways: changes in physical conditions, the supply of resources and other community of fauna (e.g., through increased predation or competition). Both physical conditions and the supply of resources are altered by high-impact conventional logging, during which the soil surface is disturbed by the introduction of dense trail systems. These impacts can be mitigated by RIL. We therefore predicted that where RIL practices are adopted, forest community structure and the composition of decomposer communities will be more similar to those in pristine (unlogged) forests than to those in conventionally logged forests. We investigated the effects of RIL on various decomposer taxa in the tropical rain forests of the Deramakot Forest Reserve and compared those with the effects of conventional logging in the adjacent Tangkulap Forest Reserve. We selected soil macrofauna and soil mesofauna (Collembola and Oribatida). We have considered the changes in abundance, species richness, and species composition of decomposer communities in relation to physical conditions and the supply of resources.

2. Materials and methods

2.1. Study sites

The study sites were production forests in the Deramakot Forest Reserve and the Tangkulap Forest Reserve in Sabah, Malaysian Borneo (5°14–30′ N, 117°11–36′ E) (Fig. 1). We use the term "reserves" to refer to land designated for production. The Deramakot Forest Reserve (551 km^2) is adjacent to the Tangkulap Forest Reserve (275 km^2), and both areas are covered by lowland mixed dipterocarp tropical rain forests. The mean attitude is 135 m at Deramakot and 83 m at Tangkulap (Ong et al., 2013). Most of soils in Deramakot and Tangkulap are classified as Lokan Association, whereas remaining is of the Dalit Association (Acres et al., 1975). Both soil associations are derived from mudstone and sandstone parent materials, where orthic acrisols are the dominant soils (Ong et al., 2013). At the time of our study (2001–2007), the forests in the Deramakot Forest Reserve were being sustainably managed with RIL practices adopted, whereas the forest in the Tangkulap Forest Reserve had already been damaged by conventional logging.

We compared macro- and mesofauna in a remnant of pristine forest with no evidence of logging having occurred, a RIL forest in the Deramakot Forest Reserve, and a conventionally logged forest in the Tangkulap Forest Reserve. The pristine remnant forest was located within the conservation area of Deramakot and had no record of logging since at least the 1980s. RIL had been practiced since 1995 in the Deramakot RIL Forest. Conventional logging was still being practiced in the conventionally logged Tangkulap forest. We established four plots in the pristine (PR) forest (0.2 ha × 4 plots), four plots in the reduced-impact logged (RIL) forest (0.2 ha × 4), and three plots in the conventionally logged (CV) forest (0.2 ha × 3). Two RIL plots were logged in 1995, and two more were logged in 2000. Precise information regarding the timing of logging in the CV plots was not recorded, but at the time of sampling, at least three years had passed since the last logging. The plots in Deramakot (PR, RIL) were about 10 km apart from the plots in Tangkulap (CV). Mean distances (minimum–maximum) among plots receiving the same treatment were 435 (177-773) (PR), 1130 (246-1836) (RIL) and 756 (582-933) (CV) m.

2.2. Soil fauna and litter layer

Soil macrofauna (>2 mm body width) was sampled by 'hand sorting' from five quadrats (each 25 cm × 25 cm) set at 10-m intervals along a line (40 m) at each of the eleven 0.2-ha plots. For each sample, the litter layer and topsoil (to a depth of 15 cm) were collected. The identification of soil macrofauna was conducted at order level (partly at family level). The fresh and dry weight of the collected litter layer was measured, and the water content of the litter layer was calculated.

For soil mesofauna, a 100-mL soil sample (20 cm^2 × 5 cm deep) including the litter layer was collected with a cylindrical core sampler at each of 10 points set at 5-m intervals along another line (45 m) in each 0.2-ha plot. The samples were placed in Tullgren funnels within a few hours of sampling. Soil mesofauna were extracted for 3 days under irradiation with 40 W electric bulbs and preserved in 80% ethanol. Collembola and Oribatida were identified to morphospecies level and counted under a microscope in the laboratory. Sampling was conducted from September to October 2003, with the exception of one plot in the conventionally logged forest, which was surveyed in March 2006. Difference in the soil animal density, diversity and community composition was not evident among sampling dates.

2.3. Vegetation survey

All living trees in eleven sites (0.2 ha) larger than 10.0 cm in trunk diameter at breast height (1.3 m, DBH) were measured in 2003, 2005, and 2007. Seino et al. (2006) previously described the tree vegetation in the study sites. Species diversity was rich in the old-growth forest and in the forest harvested by RIL, where climax and important commercial timber species of Dipterocarpaceae dominated. However, species diversity was low in the forest harvested by conventional logging methods and was dominated by pioneer species of the genus *Macaranga* (Euphorbiaceae). Basal area and above-ground biomass in the old-growth forest and the forest harvested by RIL were higher than those in the forest harvested by conventional logging methods. Floristic composition, stand structure, and above-ground biomass did not differ between the old-growth forest and the forest harvested by RIL. However, the species composition and above-ground biomass of the forest harvested by conventional logging methods were different from those of the old-growth forest and the forest harvested by RIL due to the high impacts of the logging practices.

2.4. Statistical analysis

We used generalized linear models (GLM) to compare density with the assumption of a negative binomial distribution and species richness with the assumption of a Poisson distribution (R version 2.13.0; R Development Core Team, 2011). Ordination diagrams for community structures of soil macrofauna (Collembola and Oribatida) were performed by nonmetric multidimensional scaling (NMS) using Primer v6 (Clarke and Gorley, 2006). Pooled data derived from five quadrats or 10 sampling cores were used to determine animal density. In NMS, population data were transformed to the square root $(x+1)$, and the resemblance of community composition among sites was calculated by the Bray–Curtis dissimilarity index (Bray and Curtis, 1957). Multi-response permutation