Logging Effects on Soil Macro- and Meso-Faunas in the Rain Forests of Deramakot Forest Reserve, Sabah, Malaysia

Masamichi T. Ito[1], Motohiro Hasegawa[2], Tatsuya Kawaguchi[1]

[1] *Faculty of Environment and Information Sciences, Yokohama National University, 79-7 Tokiwadai, Hodogaya, Yokohama, Kanagawa 240-8501, Japan*

[2] *Kiso Experimental Station, Forestry and Forest Products Research Institute, Fukushima 5473, Kiso, Kisogun, Nagano 397-000, Japan*

Introduction

Soil animals play important roles in every forest ecosystem in the world. Their abundance and diversity are considered to be a good indicator of forest healthiness. In Borneo, the effects of forest management have been investigated on moths (Chey 4et al. 1997), canopy arthropods (Chey et al. 1998), butterflies (Wilott et al. 2000) and beetles (Chung et al. 2000), but less frequently documented on soil animals except for termites (Eggleton et al. 1999). On the other hand, many studies which were carried out in the temperate zones of Europe, North America and East Asia revealed that forest clear-cutting caused substantial changes in soil fauna.

The purpose of our study is to detect the effects of different forest management schemes on soil fauna in tropical rain forests and to ultimately recommend a sound scheme for biodiversity conservation there.

Materials and Methods

Study sites

Ten sites were selected from forest stands under different management schemes in and around Deramakot Forest Reserve (DFR). The ten sites were grouped into three categories of management schemes: “unlogged” category including two primary-forest (PRI) sites and two sites which experienced a modest harvest by selective logging in the 1980s (80s), “RIL (reduced-impact logging)” category including two sites which were harvested by RIL in 1995 (RIL95) and two sites which were harvested by RIL in 2000 (RIL00), and “CV (conventional)” category including two sites which were continuously harvested by conventional selective logging until the time of our analysis.

Soil macrofauna

Sampling of soil macrofauna was conducted at five quadrats (each 25 × 25 cm) set at 10 m intervals along a line (40 m) in each site. Litter layer and topsoil (15 cm deep) were collected at each quadrat. The weight of litter layer and the water content were measured by drying the samples. Soil animals were immediately picked up from the soil and litter by hands in the field and preserved in 80 % ethanol. They were sorted to the groups listed in Table 1 under a stereo-microscope in the laboratory, and the sorted taxonomic groups were classified into four functional groups. Lavelle et al. (1995) recognized two important functional groups, ecosystem engineers and litter transformers. The former develops mutualism with internal microorganisms and can digest litter directly. Therefore, they affect nutrient cycling and/or soil formation, and are important in ecosystem functioning. Earthworms and termites are typical ecosystem engineers. Litter transformers such as Isopoda, Diplopoda, Blattodea and Diptera contribute to the decomposition of litter in association with external microorganisms. Predators such as Araneae, Pseudoscorpiones, Opiliones, Geophilomorpha, Symphylla and Lithobiomorpha have some roles in structuring soil animal communities. Ants act in various ways for ecosystem functioning, some as predators, others as decomposers and so on. In this study, we treated them together as one category "ants" because of the lack of information on their ecology.

Soil mesofauna

A 100 ml soil sample (20 cm^2 × 5 cm in depth) including litter layer was taken by a cylindrical core sampler at each of the ten points set at 5 m intervals along another line (45 m) in each site. The samples were put on Tullgren funnels within a few hours after sampling. Soil mesofauna was extracted for three days under irradiation of 40W electric bulbs and preserved in 80% ethanol. Among them, Collembola and oribatid mites were identified to specific level and counted under a microscope in the laboratory. Collembolan species were classified into three feeding groups, detritus feeders, fungal feeders and sucking feeders (Hasegawa 2006).

Statistical analyses

The variations in soil animal density among the forest management schemes and among the sites of each scheme were analysed by two-level nested ANOVA (group = management category, subgroup = site), separately for the total macrofauna, each functional group of macrofauna and each feeding group of Collembola. Canonical correspondence analysis (CCA) was used to examine the relation between environmental variables and the composition of the taxonomic groups of macrofauna in the study sites (ter Braak 1986). The following environmental variables were used in the analysis: the attributes based on vegetation data for all trees with DBH (maximum diameter at breast height) ≥10 cm were tree density, total basal area, above-ground biomass, the number of tree families, the number of tree species, Shannon-Wiener's diversity index, Fisher's alpha diversity index, the basal area percentage of Dipterocarpaceae, the basal area percentage of Euphorbiaceae, and the basal area percentage of Macaranga (Seino et al. 2006); soil environmental variables were the weight of organic matter and the water content in litter layer. Among them, significant variables ($p < 0.05$) were chosen by the forward selection.

Results and Discussion

Soil macrofauna

The mean densities of soil macrofauna in each of the ten sites are shown in Table 1. The mean density of total soil macrofauna was significantly higher in the unlogged sites than in the RIL sites ($p<0.05$, nested ANOVA; Fig. 1). This was primarily driven by ants, of which density was significantly higher in the unlogged sites than in the RIL and CV sites ($p<0.05$, nested ANOVA; Fig. 2). The number of orders or equivalent taxonomic groups of macrofauna was similar across the sites of three management categories (Table 1). The density of litter transformers was significantly higher in the CV sites than in the RIL and unlogged sites ($p<0.05$, nested ANOVA; Fig. 2). The density of predators was significantly higher in the CV sites than in the RIL sites ($p<0.05$, nested ANOVA; Fig. 2). The result of CCA demonstrated that the water content of litter layer and the basal area percentage of Dipterocarpaceae explained well the compositional variation of the soil macrofauna community among the sites (Fig. 3). The water content of litter and soil has been suggested as an important limiting factor for the survival of some soil animal groups (e.g., Lavelle et al. 2001). On the other hand, the dominance of Dipterocarpaceae, which has been detected as an environmental variable closely related to the structure of soil macrofauna community in tropical forests, probably reflects the forest maturity. Along the process of forest maturation, changes in a number of associated environmental factors would govern the dynamics of soil macrofauna community.

Soil mesofauna

The density and the species richness of total Collembola and oribatid mites did not differ so distinctly among the ten sites (Table 2). As for the functional groups of Collembola, detritus feeders and fungal feeders did not show significant differences in density among the management categories (Fig. 4), but the density of sucking feeders was significantly higher in the unlogged sites than in the other sites ($p<0.05$, nested ANOVA; Fig. 4). Hasegawa (2006) suggested that sucking feeders decreased in clear-cut sites and that their species composition was well related to the changes in vegetation. Sucking feeders feed on bacteria and/or the organic matter in free soil water, and therefore may be sensitive to a drought on the forest floor, which is often caused by a decrease of vegetation cover in logged sites. These results suggest that the density and the species richness of the total mesofauna were not so much affected by logging within the magnitude of current harvest schemes applied in DFR. However, the composition of Collembolan feeding groups was affected by logging, regardless of RIL or CV.

In DFR, we did not find distinct effects of logging on the density and the number of taxonomic groups in soil macrofauna (excluding ants) and mesofauna. However, the composition of functional and/or taxonomic groups varied among the sites under different forest management schemes. Various degrees of logging disturbance caused by these managements must have differently affected the relative abundances of component soil animals through changes in the above-ground plant community and/or the water content of organic matter on forest floor. We suggest that the compositional structure of soil animal community can be a potential indicator for evaluating the soundness of various logging schemes in relation to ecosystem functioning and biodiversity conservation in tropical forests.

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Table 1 Mean densities (m^{-2}) of soil macrofauna in ten sites under different forest management schemes.

Numbers in fig. 3	Soil macrofauna group	Forest management category									
		Unlogged				RIL				CV	
		PRI-1	PRI-2	80s-1	80s-2	RIL00-1	RIL00-2	RIL95-1	RIL95-2	CV-1	CV-2
	Platyhelminthes	0	0	0	0	0	0	0	0	3.2	0
32	Gastropoda	3.2	0	0	0	0	0	0	0	0	0
31	Hirudinea	0	0	0	3.2	0	0	3.2	0	0	0
	Oligochaeta (Earthworm)	83.2	12.8	48	9.6	28.8	22.4	32	48	64	38.4
	Pseudoscorpiones	28.8	35.2	22.4	28.8	12.8	3.2	38.4	25.6	35.2	35.2
28	Opiliones	3.2	6.4	3.2	0	0	3.2	0	6.4	3.2	3.2
	Araneae (Spider)	25.6	57.6	57.6	25.6	16	35.2	60.8	60.8	64	70.4
	Prostigmata	9.6	9.6	3.2	6.4	3.2	3.2	35.2	16	12.8	0
	Gamasida	3.2	12.8	0	3.2	0	3.2	16	9.6	9.6	9.6
	Oribatida	32	16	3.2	3.2	0	3.2	9.6	0	16	6.4
	Isopoda	28.8	12.8	9.6	19.2	6.4	12.8	16	9.6	28.8	73.6
	Diplopoda	32	3.2	19.2	19.2	6.4	12.8	9.6	12.8	25.6	57.6
27	Symphyla	3.2	6.4	6.4	0	0	3.2	0	0	3.2	6.4
	Lithobiomorpha	0	6.4	0	16	6.4	6.4	9.6	3.2	9.6	25.6
	Geophilomopha	6.4	6.4	9.6	6.4	3.2	3.2	9.6	3.2	6.4	6.4
	Collembola	48	67.2	115.2	28.8	32	44.8	112	92.8	57.6	73.6
	Campodeidae	6.4	9.6	16	0	0	3.2	3.2	9.6	22.4	22.4
	Japygidae	12.8	0	0	0	0	0	3.2	3.2	6.4	16
29	Thysanura	3.2	0	3.2	0	0	0	3.2	9.6	0	6.4
	Isoptera (Termite)	688	12.8	70.4	6.4	0	0	3.2	99.2	22.4	0
23	Blattodea	9.6	3.2	0	6.4	0	3.2	9.6	0	9.6	12.8
30	Dermaptera	0	0	0	0	0	0	0	0	6.4	0
25	Other Orthopetra	16	0	6.4	0	0	3.2	0	0	3.2	6.4
7	Hemiptera	22.4	48	41.6	6.4	19.2	9.6	28.8	32	19.2	22.4
22	Lepidoptera (larva)	12.8	6.4	19.2	3.2	0	3.2	3.2	0	0	6.4
15	Pselaphinae	19.2	19.2	0	0	3.2	0	22.4	3.2	28.8	0
	Staphylininae	28.8	9.6	28.8	3.2	9.6	28.8	6.4	19.2	3.2	3.2
10	Other Coleoptera (adult)	32	22.4	16	9.6	28.8	9.6	32	19.2	3.2	28.8
11	Other Coleoptera (larva)	22.4	6.4	19.2	12.8	9.6	12.8	25.6	57.6	22.4	9.6
19	Diptera (larva)	19.2	3.2	6.4	16	0	3.2	12.8	6.4	3.2	0
	Hymenoptera (Ants adult)	5357	828.8	656	176	131.2	211.2	172.8	67.2	73.6	364.8
	Hymenoptera (Ants larva)	25.6	0	0	3.2	9.6	9.6	0	3.2	0	166.4
	Insecta (unidentified)	6.4	9.6	0	6.4	0	0	0	0	0	6.4
	Total	6589	1232	1181	419.2	326.4	454.4	678.4	617.6	563.2	1078
	Total – ants	1206	403.2	524.8	240	185.6	233.6	505.6	547.2	489.6	547.2
	Number of groups	27	24	21	21	14	22	24	21	26	23

Table 2 Mean densities and species richness of Collembola in ten sites under the three categories of forest management schemes.

Management category	Site	Density (m^{-2})		Species richness		
		Average	SE	Average (per core)	SE	Total (per site)
unlogged	PRI-1	11000	1809	9.8	1.1	29
unlogged	PRI-2	9150	1282	9.8	0.9	33
unlogged	80s-1	12250	1988	10.9	1.4	34
unlogged	80s-2	16350	4104	11.4	1.1	34
RIL	RIL95-1	14000	2976	12.1	1.2	35
RIL	RIL95-2	7100	1668	7.9	1.2	33
RIL	RIL00-1	9900	2226	8.2	1.0	27
RIL	RIL00-2	10150	1886	9.3	0.9	28
CV	CV-1	7850	1883	7.9	1.1	28
CV	CV-2	16750	3366	11.1	1.1	35

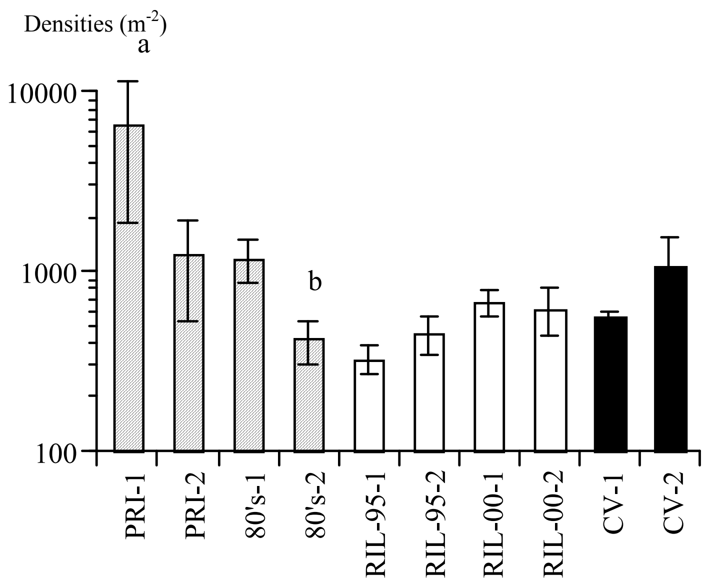

Fig. 1 Mean densities (bars: ±SE) of soil macrofauna in ten sites under the three categories of forest management schemes: “unlogged” (hatched), “RIL” (white), and “CV” (black).

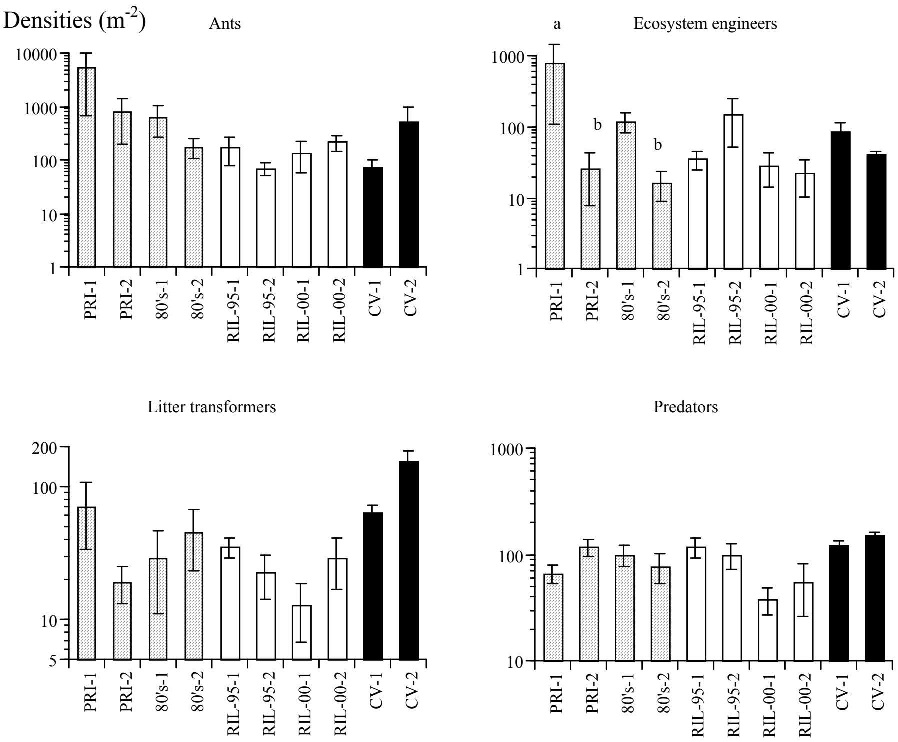

Fig. 2 Mean densities of four soil macrofauna functional groups (ants, ecosystem engineers, litter transformers and predators) in ten sites (see Fig. 1 for other explanations).

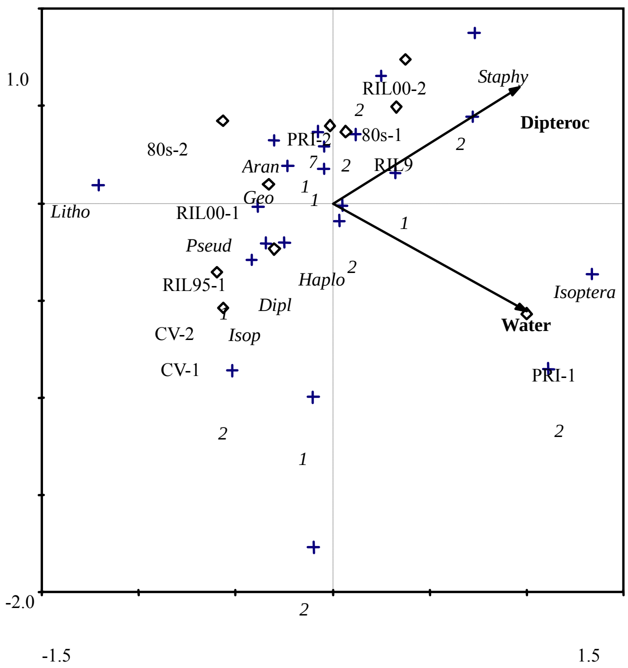

Fig. 3 Tri-plot ordination by CCA for soil macrofauna: sites (diamonds), taxonomic groups (crosses), and significant environmental variables (arrows). Dipteroc, relative basal area of Dipterocarpaceae; Water, water content in litter layer; Staphy, Staphylininae; Aran, Araneae; Litho, Lithobiomorpha; Pseud, Pseudscorpiones; Dipl, Diplopoda; Isopod, Isopoda; Haplo, Ologochaeta. Positions of other animal taxa are shown with numerals shown in Table 1.

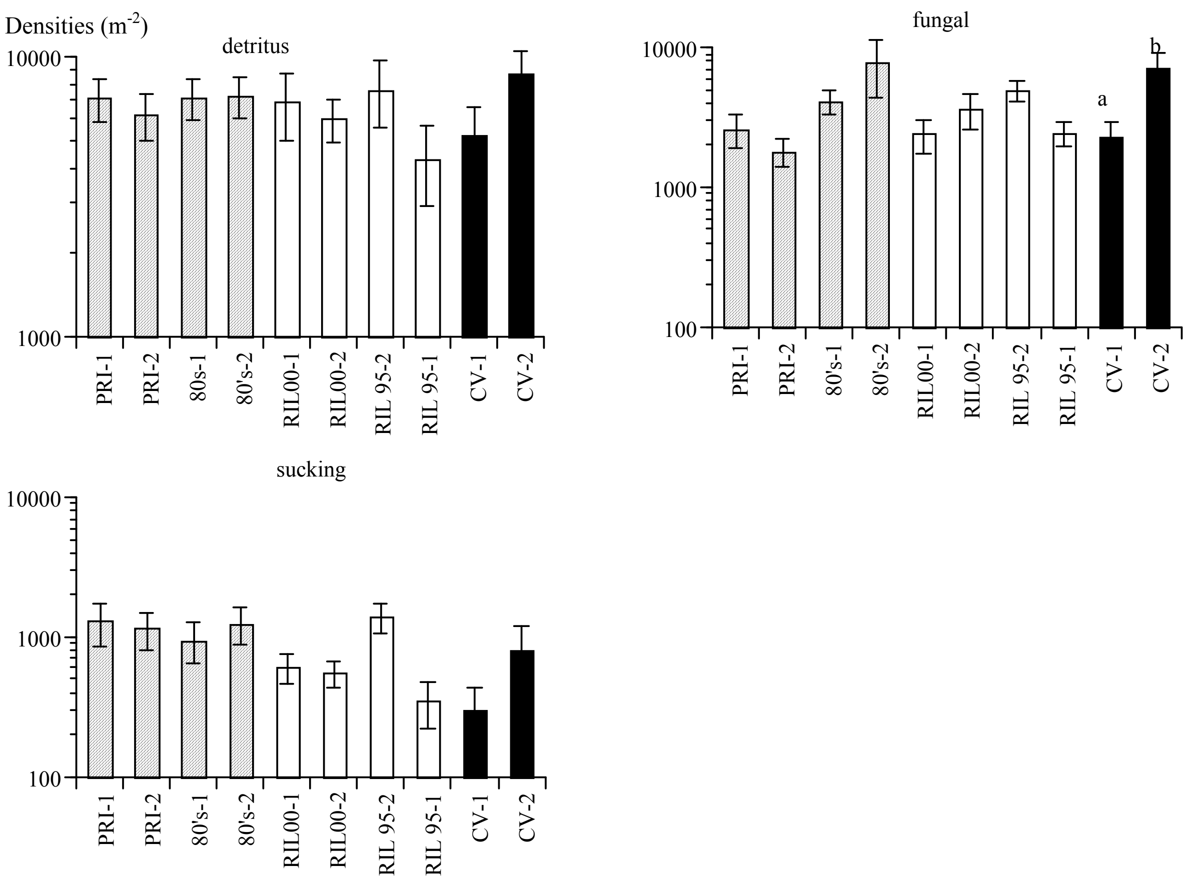

Fig. 4 Mean densities of three Collembolan feeding groups (detritus feeders, fungal feeders and sucking feeders) in ten sites (see Fig. 1 for other explanations).