Logging effects on soil macrofauna in the rain forests of Deramakot Forest Reserve, Sabah, Malaysia

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Abstract We investigated the logging effects on soil fauna in the rain forests of Deramakot Forest Reserve, Sabah, Malaysia and related the abundance and composition of the soil fauna to forest-floor condition and structures of plant communities. Research sites were divided into three categories based on logging intensity as follows: unlogged, reduced-impact logging (RIL) and conventional logging sites. The density of soil macrofauna excluding ants was not different among three logging intensities. The number of the groups (at order or an equivalent taxonomic level) of macrofauna is also similar across the three intensities. The density of ecosystem engineers (earthworms and termites) tended to be higher at the unlogged area. The densities of litter transformer and predators at conventional logging area tended to be higher than those at the other areas. The density of Staphylininae beetles is positively correlated with species richness of trees and the sum of basal area of Dipterocarpaceae. The density of spiders is negatively correlated with species richness of trees, and positively correlated with basal area of *Macaranga*. Diplopoda and Isopoda are negatively correlated with the maximum diameter of trees. Earthworms are positively correlated with the water contents of organic layers. A multivariate analysis CCA (canonical correspondence analysis) was applied to our data set to relate the variation of soil-fauna composition with environmental variables. Water content of forest-floor organic mass and the basal area of Dipterocarpaceae explained the variation of the composition. These results suggested that the abundance and diversity (alpha) of soil fauna were relatively independent of logging, but the composition of functional groups and species composition were affected by logging intensity, and related to plant community or forest floor condition.

Keywords soil macrofauna, functional groups, Deramakot Forest Reserve, ecosystem engineers, termites.

Introduction

Soil fauna plays an important role in every forest ecosystem in the world. Their abundance and diversity are considered to be a good indicator of forest health considering their important roles. In Borneo, the effects of forest management on butterflies (Willott *et al.* 2000), moths (Chey *et al.* 1997), canopy arthropods (Chey *et al.* 1998) and beetles (Chung *et al.* 2000) were investigated. However, there are few studies on the relation between soil fauna and forest management except for the work that investigated termites (Eggleton *et al.* 1999). In contrast, many studies on the relation between soil fauna and forest management have been carried out in the temperate zone of Europe, North America and East Asia. These studies detected that the harvesting method using a clear-cutting scheme caused a substantial change of soil fauna.

The purpose of our study is to determine the patterns of soil fauna in relation to different forest management schemes and recommend a suitable forest management from the standpoint of biodiversity preservation.

Materials and Methods

Ten sites were selected in and around Deramakot Forest Reserve (DFR) and they were categorized based on logging method. The category of "unlogged" had four sites, which were composed of two primary-forest sites and two sites with a history of modest harvest using a selective logging scheme in the 1970s. The category of "RIL" had four sites, which were composed of two sites with a history of the reduced-impact logging (RIL) in 1995 and two sites with RIL in 2000. The category of "conventional logging" had two sites with a history of continuous selective loggings around DFR (see Seino *et al.* in this issue). We established a line (40 m) at each site in September 2003. A quadrat (25 x 25 cm) was set at each of five points at 10 m intervals. Litter layer and topsoil (15 cm) in each quadrate were collected separately. The weight of litter layer and water content were measured after drying samples. Soil animals were immediately picked up from the soil and litter by an insect sucking tube and tweezers in the plot. Animals collected were preserved in 80 % ethanol, and sorted to main groups listed in Table 1 by using a microscope in the laboratory.

Lavelle *et al.* (1995) divided soil macrofauna into two functional groups, namely ecosystem engineers and litter transformers. The former develops mutualism with internal microorganisms and can digest litter directly. Therefore, they affect nutrient cycling or soil formation and are important in ecosystem functioning. Earthworms and termites are included in the ecosystem engineers. The latter contribute to the decomposition of litter in association with external microorganisms. Isopoda, Diplopoda, Blattodea, and Diptera are included in the litter transformer. In addition, predators have also important roles in soil ecosystems. Araneae, Pseudoscorpiones, Opiliones, Geophilomorpha, Symphylla and Lithobiomorpha are the dominant predators. Some groups of ants seem to be predators, but we ignore them from predators in this study, because of the lack of ecological knowledge of ants in this area.

Spearman's rank correlation coefficients were used for the relation between environmental variables and the densities of soil animals. Environmental variables used in this analysis were as follows, tree density, maximum diameters at breast height (DBH) of the trees greater than 10 cm DBH, sum of basal area, above ground biomass of trees, number of tree family, number of tree species, Shannon wiener's diversity index, Fisher's alpha diversity index, basal area percentage of Dipterocarpaceae, basal area percentage of Euphorbiaceae, basal area percentage of *Macaranga*, the weight of organic matter in litter layer and water content of litter layer. Environmental variables of plant communities were precisely explained in Seino *et al.* in this volume.

Principal component analysis (PCA) was used in the analysis of the relation of functional groups and the three categories of logging intensities. Canonical correspondence analysis (CCA) was used for the analysis of the relationship between environmental variables and the community structure of soil animals (ter Braak 1986). The same environmental variables as in the rank correlation analysis were used for this analysis, and forward selection was used to select significant variables ($p < 0.05$).

Results and Discussion

The mean density of total soil macrofauna over all quadrats combined per management scheme is greater at unlogged area (Figure 1). The density of ants was very high at unlogged area, consequently the density excluding ants became similar across three areas. However, we are not sure if the high density is characteristic of the unlogged area because ants are distributed heterogeneously with high standard deviations. We may need another research method for evaluating ant density more precisely (ex. nest counting or bait traps).

Hereafter, we will discuss the pattern of soil fauna excluding ants. The number of groups of macrofauna at order or equivalent taxonomic levels is also similar across all three areas (Figure 2). It seems that our results can represent the abundance of soil fauna for the lowland tropical rain forests of Sabah because the total density and number of groups are in the same order of magnitude as the low elevation on Mt. Kinabalu (Ito *et al.*, 2002). The density of ecosystem engineers tended to be higher at unlogged area (Figure 3). The greater density was due to the high density of termites at unlogged areas. In our study, termites were not divided into feeding groups, nevertheless the most of the termites that occurred in unlogged areas were found in soil layers. Thus, these termites might be dominated by soil feeders. Eggleton *et al.* (1999) suggested that selective logging appears to have relatively little effect on total termite assemblages, but they also found that soil-feeding termites were moderately affected by selective logging. The densities of litter transformers and predators at conventional logging area tended to be higher than at the other areas. PCA ordination of functional groups shows that the unlogged area is placed at a right side on the first axis, in contrast to the conventional area which is placed at a left side (Figure 4). The RIL area is placed between these areas. The eigenvalue of the 1st and 2nd axis is 0.61 and 0.39, respectively. Therefore, the ordination in the two coordinates reasonably well demonstrated the variation of the composition of functional groups. These results suggest that the total density and number of the groups of macrofauna were not much affected by logging within the magnitude of current harvest systems. However, the composition of functional groups was affected by logging methods.

The response of soil fauna to environmental variables was divided into three patterns (Table 2). The first group had a positive correlation with the species richness of trees or with the relative basal area of Dipterocarpaceae. For instance, the density of staphyliniid beetles positively was correlated with the species richness of trees and the sum of basal area of Dipterocarpaceae. The second group had a positive correlation with the relative basal area of *Macaranga*, and associated with disturbed areas after recent logging. The densities of spiders (Araneae), Lithobiomorpha and Pseudoscorpiones were negatively correlated with the species richness of trees, and positively correlated with the sum of basal area of *Macaranga*. For instance, the densities of Diplopoda and Isopoda negatively correlated with the maximum diameter of trees. These groups had a high density at relatively less disturbed areas. The third group correlated with the condition of forest floor in terms of organic mass and water content. The density of Geophilmorpha positively correlated with the amount of organic matter on forest floor. The density of earthworms positively correlated with the water contents of organic layers.

The results of CCA multivariate analysis on the variation of the composition of soil fauna ordinated in relation to the variation of environmental variables (Figure 5) demonstrated that the water content of forest floor mass and the basal area of *Dipterocarpaceae* explained the composition well. The eigenvalue of the 1st and 2nd axes was 0.087 and 0.044; cumulative percentage variance of species data of the 1st and 2nd axes was 26.5 and 40, respectively. This suggested that the community structure of soil macrofauna was influenced by the water condition in forest floor and the dominance of Dipterocarpaceae. Water content is, indeed, suggested as an important limiting factor for the survival of some groups of soil fauna elsewhere (Lavelle *et al.* 2001). In contrast, the importance of the dominance of Dipterocarpaceae, which we found, is not readily known. Probably it reflected the maturity of the forests, which is related to the dynamics of the community of soil macrofauna.

In conclusion, we did not find distinct effects of logging on the total density and the number of taxonomic groups in soil macrofauna. However, the composition of functional or taxonomical groups of soil fauna was related to the composition of above-ground plants or the water contents of organic matter in forest floor. Therefore, logging may influence the relative abundance of assembling soil fauna. We suggest that community composition of soil fauna but neither density nor the number of taxonomic groups has a potential indication value for logging scheme.

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Table 1. Mean densities (m^{-2}) of soil macrofauna in forest sites with different forest managements.

Numbers in fig. 5	Abbreviation of the plot	Category									
		Unlogged				Logged				Conventional	
		PRI-1	PRI-2	70's-1	70's-2	RIL-00-1	RIL-00-2	RIL-95-1	RIL-95-2	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
	Geophilomorpha	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 Orthoptera	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 (ant adult)	5357	828.8	656	176	131.2	211.2	172.8	67.2	73.6	364.8
	Hymenoptera (ant 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 density (m^{-2})	6589	1232	1181	419.2	326.4	454.4	678.4	617.6	563.2	1078
	total excluding ants (m^{-2})	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. Spearman's rank correlation coefficients between densities of each taxon of soil macrofauna and environmental variables. Significant coefficients ($p < 0.05$) are shown in bold.

	Staphylininae	Araneae	Lithobiomorpha	Pseudoscorpiones	Diplopoda	Isopoda	Geophilomorpha	Oligochaeta
Maximum DBH	0.555	-0.526	-0.482	-0.332	**-0.683**	**-0.648**	0.105	-0.419
Total basal areas	0.486	-0.606	-0.537	-0.197	-0.299	-0.367	0.368	-0.219
Above ground boimass	0.312	**-0.661**	-0.352	-0.271	-0.348	-0.447	0.316	-0.413
Species richness of trees	**0.866**	**-0.767**	**-0.756**	**-0.775**	-0.156	-0.469	-0.389	0.043
Relative basal area of Dipterocarpaceae	**0.904**	-0.483	**-0.753**	**-0.689**	-0.146	-0.453	-0.191	-0.043
Relative basal area of Macaranga	**-0.848**	**0.777**	**0.722**	**0.677**	0.152	0.385	0.184	0.055
Weight of litter layers	-0.549	0.287	0.512	**0.720**	0.085	0.447	**0.737**	-0.328
Water contents of litter layers	0.511	0.214	-0.525	0.086	0.354	0.177	0.461	**0.760**

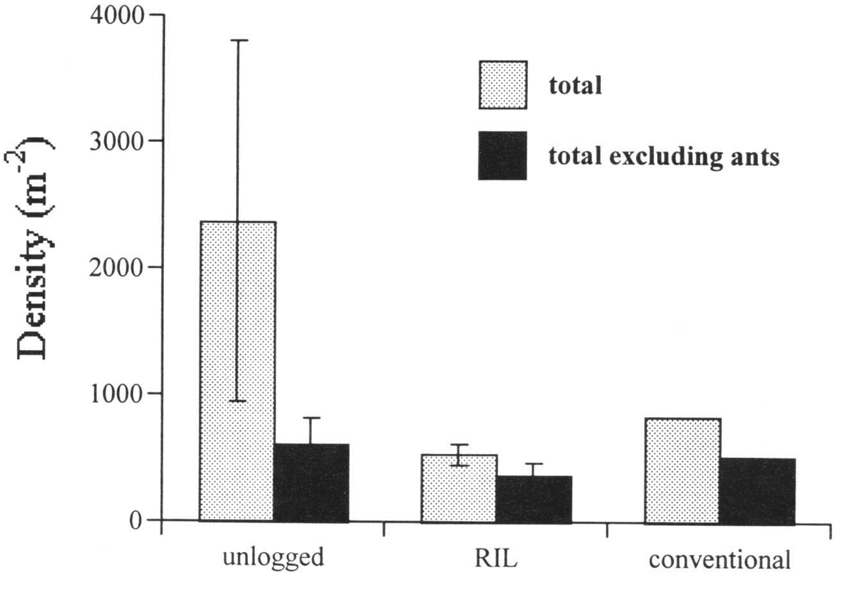

Figure 1. Densities of soil macrofauna in three forest management categories. Bars indicate standard errors.

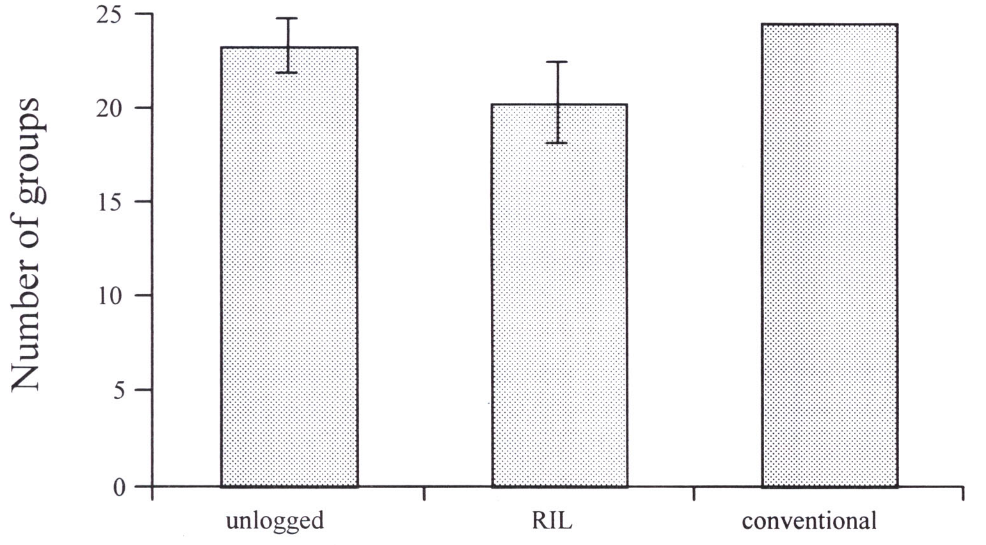

Figure 2. Number of groups of soil macrofauna in three forest management categories. Bars indicate standard errors.

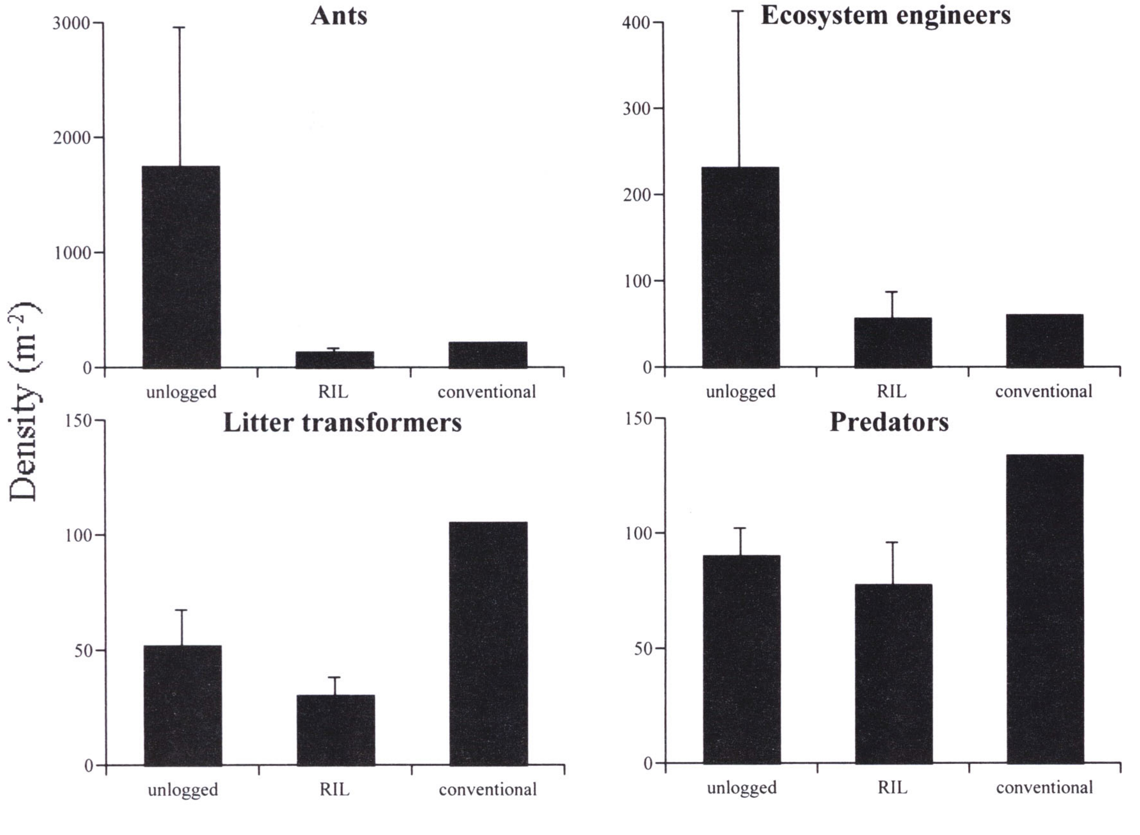

Figure 3. Densities of ants, ecosystem engineers, litter transformers and predators in three forest management categories. Bars indicate standard errors.

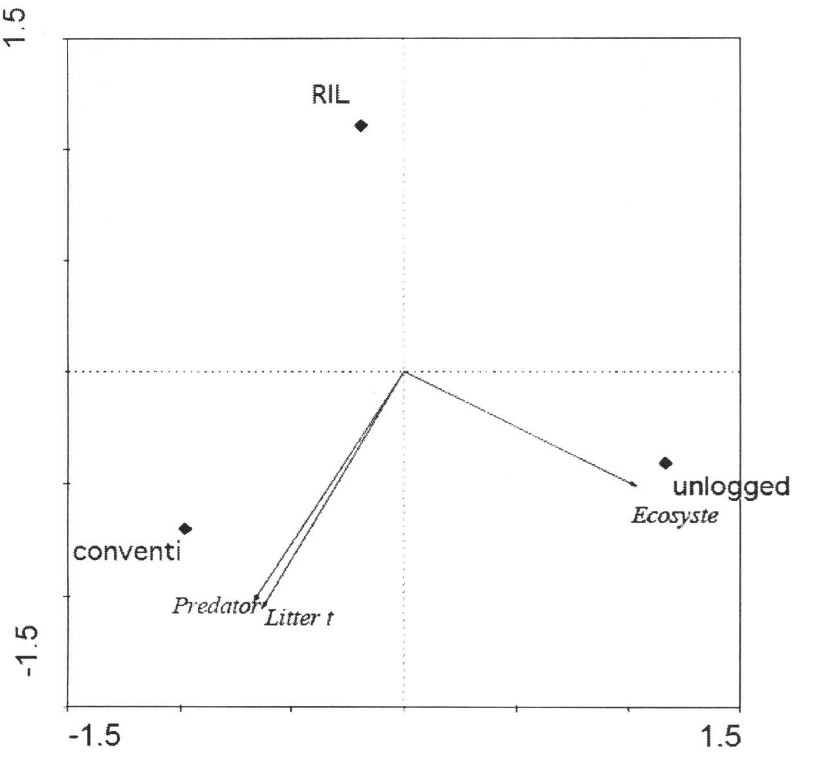

Figure 4. PCA ordination plots for functional groups of soil macrofauna. Diamonds show the positions of communities with forest management categories. Arrows show the directions of the increase of densities for three functional groups.

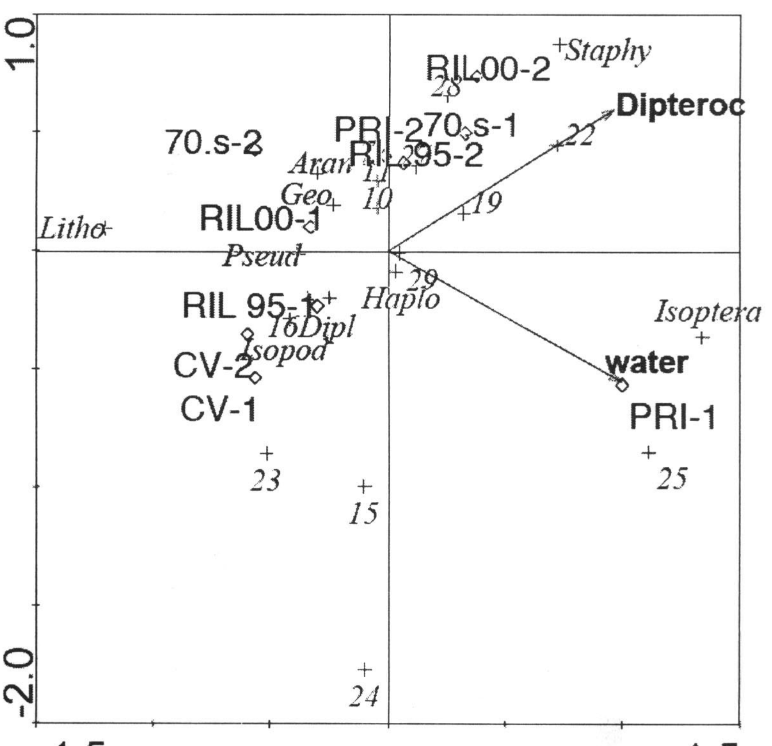

Figure 5. CCA ordination plots for soil macrofauna. Diamonds show the positions of communities with forest managements. Crosses show the positions of the taxonomical groups. Significant environmental variables are shown by arrows. Dipterocap, relative basal areas of Dipterocarpaceae; water, water contents in litter layers; Staphy, Staphylininae; Aran, Araneae; Litho, Lithobiomorpha; Pseud, Pseudoscorpiones; Dipl, Diplopoda; Isopod, Isopoda; Haplo, Oligochaeta. Positions of other animal taxa are shown by numerals, which can be referred in Table 1.