Assessment of the bioindicator values of flying insects at a higher taxonomic level for different logging schemes in the lowland tropical rain forests of Deramakot, Sabah, Malaysia

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Abstract The importance of the ecosystem services of, and the biological values of tropical forests are increasingly recognized amid drastically changing landscapes in the tropics. There is an urgent demand for establishing an appropriate environmental assessment method to keep healthy ecosystem functions and biodiversity along with sustainable forest use based on ecological principles. In this study, we tried to assess logging disturbance using several flying insect groups with their abundance in managed lowland tropical rain forests, Deramakot Forest Reserve (DFR), Sabah, Malaysia, with consideration of seasonal changes. We used a bait trap system to collect flying insects in several strata from the ground to a canopy in four seasons (periods) throughout a year in five forests with different logging histories/intensities. All the studied insects at a lower taxonomic level fluctuated seasonally in their abundance, while the family composition which took into account the relative abundance of families of trapped insects was relatively constant across the plots and the seasons. Although, effects of logging on the abundance of flying insects were distinct at an intensively logged plot, there was no clear difference among undisturbed plot and the moderately disturbed plots harvested by reduced-impact logging (RIL). The abundance of flying insects at higher taxonomic level has a potential of indicating logging disturbance.

Introduction

An alteration of tropical forests has been an issue in conservation ecology since the 1980s (Bowles *et al.*, 1998). The importance of ecosystem services and biological values provided from tropical forests has been pointed out by scientists and more recently citizens are increasingly aware of the importance of tropical forests. Therefore, scientific knowledge can be better disseminated to the society for the sustainable use of tropical forests in the world. Main driving forces of deforestation are population pressure, policies of governments (Laurance, 1998) or economic development (Wilkie *et al.*, 1992) and combinations of these. Under these circumstances, it is a challenging task for us to develop policies and schemes of the conservation of tropical forests to keep healthy ecosystem functions and biodiversity in harmony with the sustainable use of these forests (Kleine and Heuveldop, 1993). To achieve this goal, we need to demonstrate the tolerance level of forests for human use based on ecological principles (Bawa, 2004).

The first step to meet this challenge is to scientifically and practically assess the current conditions of disturbed and undisturbed environments. Various bioindicators have been applied as useful tools to assess living conditions for organisms, traditionally in aquatic environments (Rosenberg *et al.*, 1986) and recently in terrestrial environments (Van, 1998; Baldi, 2003; Ekschmitt, 2003 Woodcock *et al.*, 2003). Invertebrates have an advantage as bioindicators, because of being ubiquitous in a wide range of environments and of being moderate in the growth rate, population turnover and mobility to record (Hodkinson *et al.*, 2005).

There are various approaches in bioindicator assessment. Some focus on certain taxa, but others measure the diversity of the whole community at the level of species or higher taxa (McGeoh, 1998; Hodkinson *et al.*, 2005). Naturally, the finer the taxonomic resolution is, more fine-scaled information on the environment will be gained. However, such a fine-scale assessment at the species level is impractical when using highly diverse taxa such as insects. Identification of species is almost impossible for non-experts and even for experts the identification work necessitates a large amount of labor and time (Oliver, 1996; Lawton *et al.*, 1998; Baldi, 2003; Keith, 2004). Instead, practically and economically reasonable approaches of using higher taxa (family or order) or functional groups are recently invented and demonstrate scientifically reasonable results (Baldi, 2003; Deans, 2005).

In this report, we present preliminary results of our study carried out in Deramakot Forest Reserve (DFR), Sabah, Malaysia from 2003 to 2004. In DFR, various logging regimes were historically applied to different stands of tropical lowland rain forests. Effects of different degrees of logging disturbance on insect abundance were compared across an array of forest stands that differ in the method of logging operation and the time elapsed after logging.

Materials and Methods

Location and climate of study site

Deramakot Forest Reserve (DFR), Sabah, Malaysia (5°19'- 20'N, 117°20'-42'E), covers 55,000 hectares in the east of central Sabah. The climate is humid equatorial, with low variance in monthly mean temperature with a monthly mean of about 26°C. Although the climate is humid equatorial, monthly rainfall fluctuates seasonally, being higher in November to February but lower in March to July by the Northeast and Southwest Monsoon, respectively (Town and Regional Planning Department, Sabah, 1998). The forest of DFR is classified as the *Parashorea tomentella-Eusideroxylon zwageri* type, dominated by dipterocarps such as *Parashorea tomentella, Shorea johorensis, Dryobalanops lanceolata* and *Dipterocarpus caudiferus*, which together make up 40 % of bigger trees (Chey, 2002).

Logging history in DFR

Logging in DFR began from the southern part, along the Kinabatangan River, in the 1950s. The initially adopted logging method was the Malayan Uniform System, which allowed harvesting of all commercial timber over 45 cm in DBH (Diameter at Breast Height) and following systematic poisoning to unwanted species for promoting the natural regeneration of saplings and seedlings of commercial trees. This was modified in 1971 to the Sabah Uniform System along with the timber boom that started in the late 1960s (Kleine and Heuveldop, 1993). In the Sabah Uniform System, the minimum DBH for harvesting was raised to 60 cm and felling was assumed to be at 60-year intervals. As a result of the use of heavy machineries and intensity of logging, a large tract of the forests of Sabah was altered.

In 1989, the Sabah Forestry Department, assisted by the German Government, started a project aimed at introducing sustainable management for timber production, soil conservation, non-timber forest produce and conservation of native flora and fauna in DFR. The introduced logging operation is called reduced-impact logging (RIL). RIL is a kind of selective logging, which lays down various guidelines for sustainable forest use, e.g., setting of stream buffer zones, preservation of potential crop trees, and damage assessment after harvesting (Sabah Forestry Department, 1998).

Study plots

To assess the recovery from and the impacts of logging on various components and functions of lowland tropical rain forest ecosystem, a total of ten 0.2-hectare study plots were established in different forest compartments in and near DFR by colleagues of plant ecology (see Seino *et al.* in this volume): those plots were classified into five groups, each with two replicate plots, under different regimes of disturbance (i.e. harvest method) in logging operation and the time elapsed after logging. We chose one of the two replicate plots from each group for sampling flying insects. In this paper, the disturbance regimes were specified by two factors, logging method (RIL or CM (conventional method) referring to non-RIL) and the time after logging. The five plots for insect collection were named according to the disturbance regimes: Primary, the forest with no impact of logging (5°22'7.1"N, 117°25'9.73"E); CM-70s, the forest harvested in the 1970s by CM (5°22'2.26"N, 117°26'1.96"E; No. 54); RIL-95, the forest harvested in 1995 by RIL (5°21'5.42"N, 117°25'4.45"E; No. 60); RIL-00, the forest harvested in 2000 by RIL (5°23'8.88"N, 117°18'9.5"E; No. 63); and CM-con, the forest intermittently continuously harvested by CM (5°23'8.64"N, 117°18'9.19"E; outside of DFR).

Insect sampling

We employed a bait trap specially designed by Toda (1977) for sampling flying insects in the above-ground forest space. To collect mainly fruit flies (Drosophilidae) the traps were baited with fermented banana (ca. 170 g per trap), but non-drosophilid flies (Diptera), beetles (Coleoptera), bees and wasps (Hymenoptera) were also collected in abundance. Insects of other orders were also collected but with lesser abundance.

In order not to disturb the forest floor of study plots by repeated visits to the trapping sites, we selected a tree or two trees beside each plot for setting the banana traps. The traps were set vertically from the understory to the canopy: the lowest trap was set at 0.5 m above the ground surface, the next at 1.5 m, and others at 5 m intervals up to the canopy with the top trap varying in height according to the canopy height of the forest (Table 1). Some (up to four) upper traps were suspended from the same rope with a pulley that was hung from a bough of the selected tree, but the lowest two were tied directly to the trunk of the same or a nearby tree (Figure 1).

We conducted sampling four times, in July to August and in October to November 2003, and in January to February and in April to May 2004. During each sampling period trapped insects were collected and trap baits were renewed three times at 10-day intervals. All samples were preserved in 70 % ethanol and temporarily brought to Hokkaido University (Japan) for identification purposes. Collected insect specimens were identified to family for Diptera and Coleoptera but to order for the others except Hymenoptera, which was classified into honey bee, stingless bee and parasitic wasp.

Results and Discussion

We collected, in total, 82,318 individuals of ten orders by the four monthly samplings: 20,514 individuals of 8 orders in July to August, 27,393 individuals of nine orders in October to November, 17,662 individuals of nine orders in January to February and 16,749 individuals of nine orders in April to May. Table 2 shows the numbers of individuals of each family (functional group for Hymenoptera) or order collected at the five study plots in each sampling period. Since the number of traps varied among the study plots (Table 1), the abundance of trapped arthropods at each plot was expressed as the number of individuals collected per trap in Figure 2.

The abundance of trapped arthropods varied among the plots and seasons. The difference among the plots was large (more than 130 in standard deviation) in relatively dry seasons (July to August, October to November and April to May) and small (21.5 in standard deviation) in the rainy season (January to February). Such clear seasonality has been observed in the abundance of tropical insects (Wolda, 1980; 1988; Kato *et al.*, 1995). This suggests that even in the tropics, environmental assessment using arthropods community should be done across a year. Although the abundance-rank orders of the plots varied among the seasons, in general, moderately disturbed plots, RIL-95 or RIL-00, had the most abundant number of trapped insects and the heavily disturbed plot, CM-con, had the least number of insects.

In spite of the variation in total abundance, the composition using relative abundance of families of trapped arthropods was relatively constant across the plots and the seasons. Drosophilidae, Nitidulidae and Staphylinidae in combination made up nearly 90 % of the total catch at every plot. This may indicate the efficiency of bait traps for collecting insects from distance. Further precise identification of the collected samples (i.e. species level) is need for evaluating the changes of community structure along with logging disturbance regimes.

We suggest that the bait trap method which we have used here can effectively collect flying insects with minimal support from various strata of a tropical forest. Abundance of collected arthropods was prominently decreased at heavily disturbed plot, CM-con. Relatively cost effective assessment of using bioindicator at higher-taxonomic level has a potential of evaluating logging disturbance. We are still identifying collected insects for selecting taxa of such bioindicator values. Our results will be reported elsewhere.

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Table 1. Summary of trapping site at each study plot.

Plot	Canopy height (m)	Species of trap-site trees	Trap heights (m)
Primary	31.5-36.5	*Polygclaccae affine* *Shorea exelliptica*	0.5, 1.5,6.5, 11.5, 16.5 21.5, 26.5, 31.5, 36.5
CM-70s	26.5-31.5	*Lithocarpus sp.* *Shorea macroptera*	0.5, 1.5,6.5, 11.5, 16.5,21.5 26.5, 31.5
RIL-95	26.5-31.5	*Shorea sp.*	0.5, 1.5, 6.5, 11.5, 16.5, 21.5, 26.5
RIL-00	26.5-31.5	*Dipterocarpus sp.* *Durio* sp.	0.5, 1.5, 6.5, 11.5, 16.5 21.5, 26.5
CM-con	21.5-26.5	*Shorea parvifolia*	0.5, 1.5, 6.5, 11.5, 16.5, 21.5

Table 2. Numbers of arthropod individuals collected in July to August, in October to November, 2003, in January to February and in April to May, 2004, separately shown for each family or order.

Order	Plot Family	Primay	CM-70s	RIL-95	RIL-00	CM-con
July to August						
Diptera	Drosophilidae	3346	3053	1891	3378	1061
	Phoridae	169	60	96	164	116
	Sciaridae	16	3	4	6	6
	Muscidae	16	10	6	19	6
	Neriidae	29	2	1	1	6
	Total	3576	3128	1998	3568	1195
Coleoptera	Nitidulidae	1375	717	816	908	290
	Staphylinidae	618	601	361	346	328
	Lucanidae	0	32	9	1	0
	Curculionidae	2	1	0	0	0
	Scolytidae	7	1	1	0	7
	Total	2002	1352	1187	1255	625
Hymenoptera	Parastic wasp	95	66	41	104	51
	Honey bee	3	1	1	0	0
	Stingless bee	52	42	34	53	35
	Wasp	4	1	0	2	0
	Total	154	110	76	159	86
Hemiptera		1	0	0	0	0
Blattaria		2	4	7	8	4
Lepidoptera		2	2	0	0	3
Araneae		2	4	1	1	1
Orthoptera		0	0	0	1	0
	Total	5739	4600	3269	4992	1914
October to November		4735	2289	3822	2576	2132
Diptera	Drosophilidae	195	241	139	151	97
	Phoridae	83	85	23	71	2
	Sciaridae	13	6	21	13	3
	Muscidae	6	3	2	24	5
	Neriidae	12	2	8	4	0
	Syrphidae	5044	2626	4015	2839	2239
	Total	2240	764	1968	1409	955
Coleoptera	Nitidulidae	396	376	293	370	350
	Staphylinidae	1	3	0	18	0
	Lucanidae	1	3	3	0	4
	Curculionidae	2	3	5	1	3
	Scolytidae	4	0	0	0	1
	Histeridae	1	0	0	5	0
	Total	2645	1149	2269	1803	1313
Hymenoptera	Parastic wasp	246	212	199	321	174
	Honey bee	4	2	8	1	1
	Stingless bee	28	56	15	29	26
	Wasp	2	2	0	0	0
	Total	280	272	222	351	201
Hemiptera		21	8	12	22	2
Blattaria		2	15	10	7	3
Lepidoptera		1	2	0	2	0
Araneae		4	3	1	1	1
Dermaptera		0	0	0	5	0
Acarina		0	2	0	1	0
	Total	7997	4077	6529	5031	3759

January to February						
Diptera	Drosophilidae	3086	2464	2523	2255	1827
	Phoridae	29	104	136	75	70
	Sciaridae	22	9	43	10	5
	Muscidae	18	17	13	10	3
	Neriidae	8	1	2	1	0
	Syrphidae	1	1	0	3	0
	Total	3164	2596	2717	2354	1905
Coleoptera	Nitidulidae	615	651	416	636	420
	Staphylinidae	184	291	333	176	365
	Lucanidae	0	2	0	2	0
	Curculionidae	0	2	5	4	8
	Scolytidae	3	0	0	0	0
	Histeridae	0	1	1	1	0
	Total	802	947	755	819	793
Hymenoptera	Parastic wasp	93	132	55	68	85
	Honey bee	3	1	0	1	3
	Stingless bee	9	58	23	37	65
	Wasp	3	0	1	0	1
	Total	10	191	79	106	154
Hemiptera		6	8	9	3	28
Blattaria		11	14	20	16	36
Lepidoptera		1	0	0	2	7
Araneae		1	3	1	2	1
Dermaptera		0	1	1	0	0
Acarina		1	0	0	0	0
	Total	4094	3760	3582	3302	2924

April to May		1728	2943	1353	2121	481
Diptera	Drosophilidae	40	17	16	96	27
	Phoridae	3	4	4	8	4
	Sciaridae	40	20	13	24	4
	Muscidae	2	0	0	1	1
	Neriidae	1813	2984	1386	2250	517
	Total	832	279	549	598	386
Coleoptera	Nitidulidae	1587	1179	743	755	450
	Staphylinidae	2	16	2	50	1
	Lucanidae	3	2	2	3	17
	Curculionidae	16	6	3	4	11
	Elateridae	4	8	1	2	3
	Scolytidae	0	0	0	1	0
	Cerambycidae	0	0	1	0	0
	Total	2444	1488	1301	1413	868
Hymenoptera	Parastic wasp	30	16	13	32	21
	Honey bee	0	3	0	0	2
	Stingless bee	4	39	14	22	8
	Wasp	0	2	0	0	0
	Total	34	60	27	54	31
Hemiptera		3	2	4	5	0
Blattaria		2	5	5	15	3
Lepidoptera		2	3	1	1	3
Araneae		10	0	8	1	3
Acarina		1	0	0	0	0
Orthoptera		0	0	0	2	0
	Total	4309	4542	2732	3741	1425

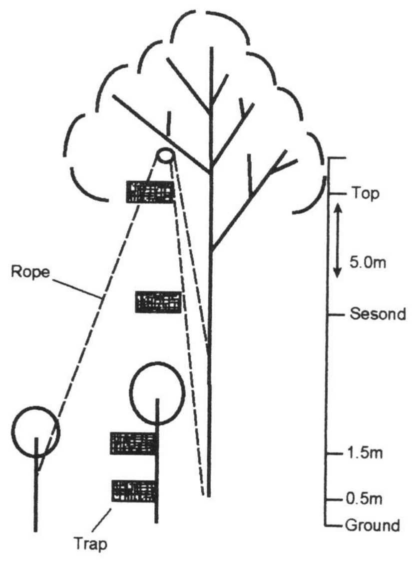

Figure 1. Trap setting by a rope-pulley system.

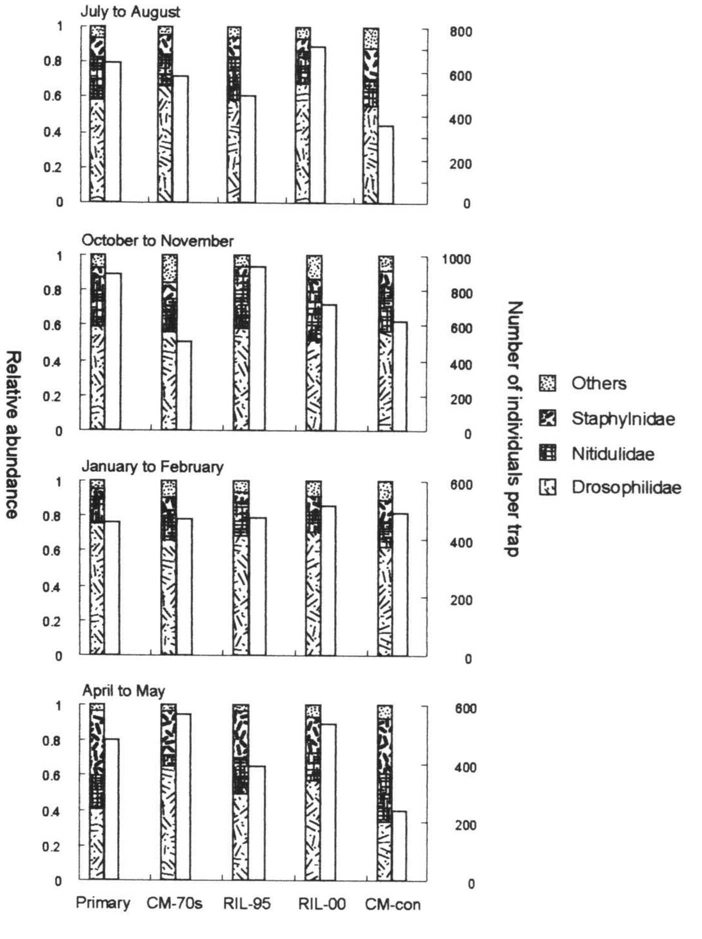

Figure 2. The relative abundance composition at the family level (left-side, shaded bar) and the number of individuals per trap (right-side, white bar) at each study plot in July to August, in October to November, 2003, in January to February and in April to May, 2004 (from top to bottom).