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CANOPY STRUCTURE AND INSECT COMMUNITY DISTRIBUTION IN A TROPICAL RAIN FOREST OF WEST KALIMANTAN

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ABSTRACT. The canopy structure and spatial distribution of flying insects in a riverside forest canopy were studied. Based on insect composition, the canopy was divided into four areas: upper open space of a canopy gap, inside the canopy, forest floor, and river surface. Thysanoptera were abundant in the upper open space, while Coleoptera were abundant near the forest floor. Insect composition was intermediate inside the canopy. The horizontal canopy structure affected insect distribution as did the vertical structure. The community at the river surface was rich in aquatic insects. However, the distribution of aquatic insects was limited only to the river surface.

INTRODUCTION

Many ecological activities including flowering, pollination and herbivory occur in the canopy of a forest. These activities are affected by environmental factors determined by the canopy structure (Koike *et al.* 1990). For some insect taxa, the foliage of the canopy supplies food, and though dense foliage may be an obstacle for flight, it also may be a shelter from predators and strong winds. Thus the foliage distribution should be considered as a kind of map of the canopy, when describing the spatial distribution of insect activities.

Many studies have been conducted on insect distribution in a forest canopy (Sutton & Hudson 1980, Sutton *et al.* 1983, Rubik 1993, Fukuyama *et al.* 1994, Kato *et al.* 1995). Toda (1977, 1987) studied the Drosophilidae community in forest canopies in cool temperate forests with reference to the canopy structure. He found two community types: an upper canopy community of sap feeders and a forest floor community of fungus feeders. Most earlier studies, however, used height from the ground to indicate the trap position in the canopy. Tropical rain forests usually have a horizontally heterogeneous canopy structure (Koike & Syahbuddin 1993, Koike 1994), and the horizontal distribution of the insect community in the foliage-canopy has not yet been studied. A quantitative analysis between the spatial distribution of foliage density and insect distribution has not yet been made. This may be caused by the difficulties in measuring foliage density distribution in a tall canopy.

Many trap methods have been used to study insect distribution in a forest canopy. Although ultra-violet light traps are often used to assess insect fauna in canopies (Sutton & Hudson 1980, Sutton *et al.* 1983, Casson & Hodkinson 1991, Kato *et al.* 1995), light spreads over a wide area if there is open space around the trap, and a wide range of insects will be trapped. Since light may disturb the spatial distribution of insects, it is difficult to obtain a high spatial resolution of insect distribution by this method. Insecticide fogging is also used to assess insect fauna (Roberts 1973, Casson & Hodkinson 1991, Kitching *et al.* 1993), but spatial resolution is also low. We therefore used a two-dimensional arrangement of sticky traps to measure the spatial distribution of flying insects in a tropical rain forest canopy.

METHODS

A natural tropical rain forest along the Daid River in West Kalimantan (0°43′N, 110°12′E, alt. 60 m) was studied in August 1991 (Suzuki

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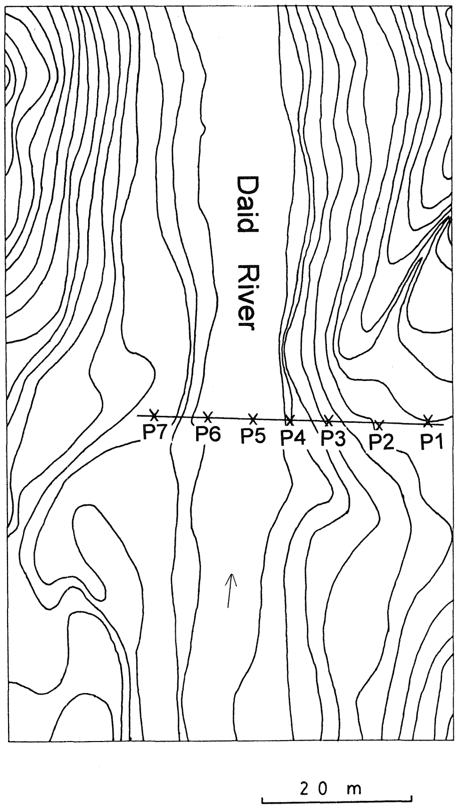

FIGURE 1. Topography of the study site (Suzuki *et al.* 1997). Contours are at 1 m intervals. Daid River is 60 m above sea level. P1–P7 are horizontal positions of traps.

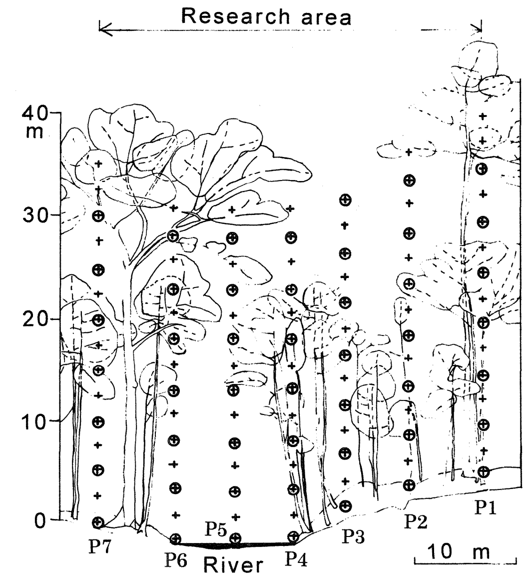

FIGURE 2. Canopy diagram of the studied section. Small trees and shrubs were neglected. Traps were arranged at the positions of open circles. Hemispherical photographs were taken at the plus marks to determine canopy structure and light conditions.

et al. 1997). The mean annual precipitation at Sangau, near the study site, is 3,111 mm, and the mean temperature is 26.4°C. The study was conducted at the end of the dry season. No prominent flowering was found during this period. The study site was a fragmented primary forest surrounded by a partially logged area. *Shorea stenoptera* (tengkawang tungkul) and *Tristania obovata* were abundant along the river. Slopes behind this forest were covered by lowland dipterocarp forest.

A 40 m line was set across the river (FIGURE 1), and the canopy above this line was studied (FIGURE 2). A rope system to hold traps and take photographs to determine foliage-canopy structure was established (FIGURE 3). At first a ring rope, **A**, was set. This rope could be maneuvered to determine the horizontal position of other vertical ropes, **B–E**. Vertical lines were placed at approximately 5 m intervals in a horizontal direction.

The foliage was measured by canopy tomog-

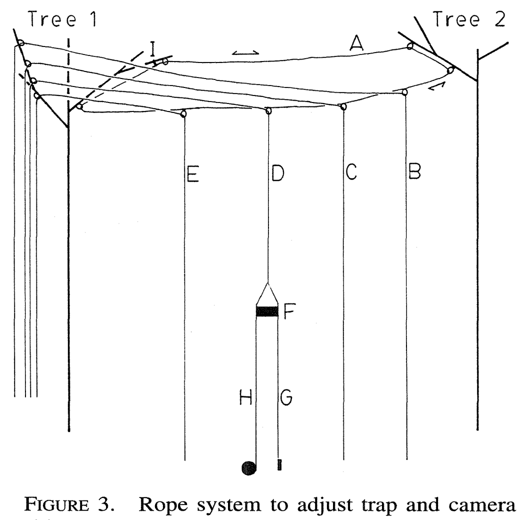

FIGURE 3. Rope system to adjust trap and camera positions. Horizontal position is adjusted by the ring rope **A**, vertical position by **B–E**. **F** is a camera with gyro horizon, **H** a tape measure and **G** an electric cable to release camera shutter. Seven vertical ropes (i.e., **B–E**) at 5 m intervals were used in the study. All traps were set simultaneously with these seven ropes. A similar rope system is available for use in Sarawak, Lambir Hills National Park (Koike 1994).

raphy (Koike 1985). A camera with a hemispherical lens on the gyro horizon was maneuvered with the rope system, which was used to collect insects. Upward hemispherical photographs were taken at 2.5 m vertical intervals. Gap fractions on the photographs were measured and total foliage amounts in various directions were calculated from the data. The two-dimensional distribution of foliage density was determined using the least squares method. Relative light intensity was also determined from the same photographs (Anderson 1964).

Sticky traps (trade name Haitori Ribbon) of size 3.8 cm by 70.0 cm were made of double-sided adhesive paper. They were set on the vertical rope at 5 m intervals (FIGURE 1) for 24 hours. No rain fell during trapping. The sticky traps were then washed with kerosene, and the trapped insects were kept in ethanol. Since complete identification of insect species was difficult, identification was made at the order level. Body size was also measured for classification. Body size class was classified in logarithmic intervals, 0–1 mm, 1–2 mm, 2–4 mm, 4–8 mm, and over 8 mm. Insects of different body size classes were treated as different taxa in community classification analysis.

The two-way indicator species analysis (TWINSPAN, Hill 1979) was used to classify insect communities. This procedure aims to automate the plant sociological method that classifies plant communities (Mueller-Dombois & Ellenberg 1974). In this computer program, traps are ordinated by reciprocal averaging. Distinctive taxa, which appear on only one side of the first ordination axis, are chosen. The taxa distributing throughout the ordination axis are neglected, and only the distinctive taxa are used in the subsequent ordination. This ordination makes it easy to separate traps into two groups.

TWINSPAN can essentially use only 'existence and absence' data of taxonomic composition. However, to consider the differences in quantity and to avoid the effect of accidental appearances of taxon, the analysis often used 'pseudo-species.' The same taxon with different individuals numbers are counted as different 'pseudo-species'. We set the five levels of 'pseudo-species' in this analysis: 1 individual level, 2–3 individuals level, 4–6 individuals level, 7–15 individuals level, and over 16 individuals level. For example, in a given trap, if 6 individuals of 2–4 mm body size class Coleoptera were caught, this trap had four 'pseudo-species'. These are 1 individual level, 2–3 individuals level, and 4–6 individuals level. In another trap, if 2 individuals of the same size class Coleoptera were caught, this trap had two 'pseudo-species' of 1 individual level and 2–3 individuals level. The first two 'pseudo-species' are common between both traps, but the 'pseudo-species' of 4–6 individuals level is different. Thus it is possible to consider equality of taxonomic composition and differences in quantity.

RESULTS AND DISCUSSION

A canopy gap occurred at the center of the section above the river (FIGURE 4a). Dense foliage of the lower layer below 15 m was found in the studied section. Lower layer foliage was absent just above the river. Light intensity generally decreased towards the forest floor (FIGURE 4b), but light streams down into the canopy gap. Such a canopy structure with dense foliage below 15 m and sparse distribution of the upper canopy crown is common in tropical rain forests in Southeast Asia (Koike & Syahbuddin 1993, Koike 1994).

Spatial distribution of the number of trapped individuals in the studied section is shown in FIGURE 5. Many Coleoptera and Diptera individuals occupied the lower layer. Hymenoptera and Thysanoptera were abundant in the upper layer and in the gap. Trap samples were usually composed of diverse species. The exception was a species of Chrysomelidae (Coleoptera), of which 84 individuals were collected simultaneously at the river surface trap, probably due to migration flight.

Correlation coefficients were calculated between environmental factors and the individual numbers of major taxa (TABLE 1). Since the individual numbers used in the analysis were classified by order level identification, the individual number of the dominant species in each order should contribute most to the analysis. Thysanoptera and Hymenoptera were abundant in areas with high light intensity and in open space in the upper canopy. Diptera and Coleoptera were abundant in the lower layer. Foliage showed negative correlation in Thysanoptera, Hymenoptera and Diptera. Open space without foliage may be a corridor for these flying insects; however, the negative correlation was not significant for Hemiptera and Coleoptera. These taxa usually have hard forewings and may not fly as often as previously mentioned taxa. The mass collection of a Chrysomelidae species at the river surface suggests that open space above the river may facilitate migration flight even for terrestrial insects.

The insect communities in the studied section were divided into four types by TWINSPAN. The Type A community was in the upper open area, especially in the canopy gap (FIGURE 6) where Thysanoptera and Hymenoptera were abundant (TABLE 2). Type C was near forest

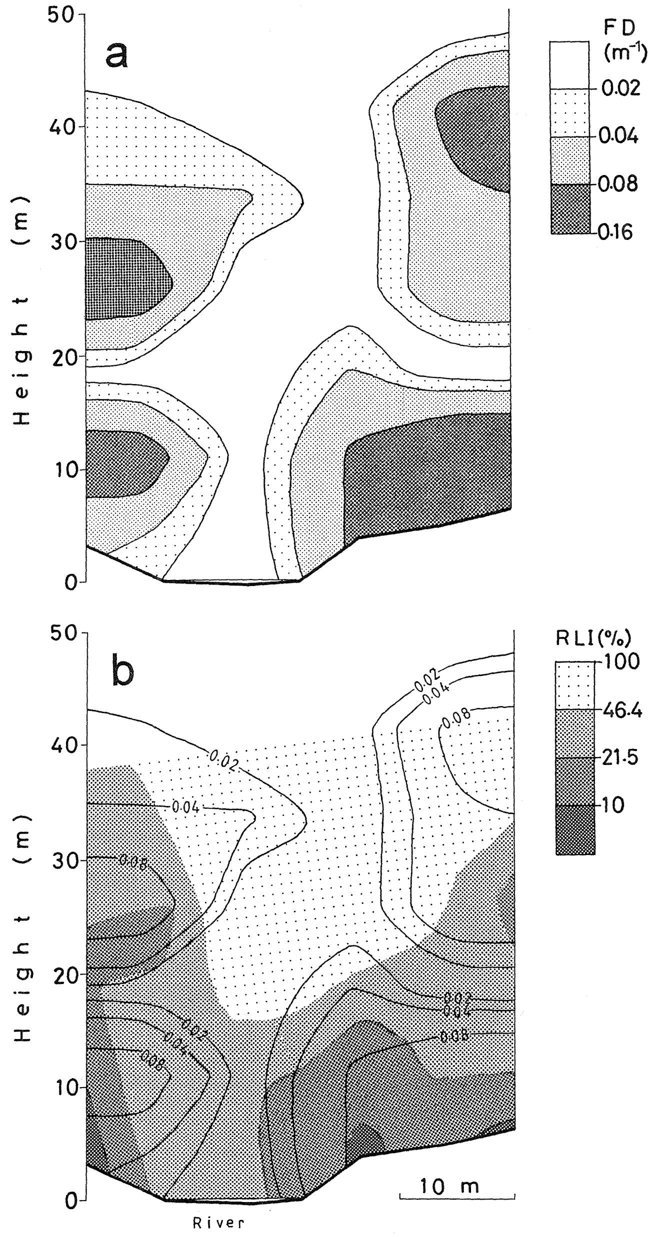

FIGURE 4. Foliage density (FD, **a**) and relative light intensity (RLI, **b**) of the studied canopy section. Background contour lines in **b** indicate foliage density distribution. Foliage density is the expected number of leaves penetrated by a 1 m line. The spatial resolution of foliage distribution was 5 m by 5 m in the horizontal and vertical. The RLI obtained by hemispherical photographs represents openness of the canopy above the position.

floor where Coleoptera were abundant. Type B was in the mid canopy between forest floor and upper canopy surface. Insect composition was intermediate between the open space and forest floor. Type D was only at the river surface, where aquatic insects, Ephemeroptera and Trichoptera, were distinctive. Aquatic insects were not distributed far from the river either in the horizontal or vertical directions.

Although open space above 40 m was not studied in this research, the open space in the upper canopy gap, where samples were taken,

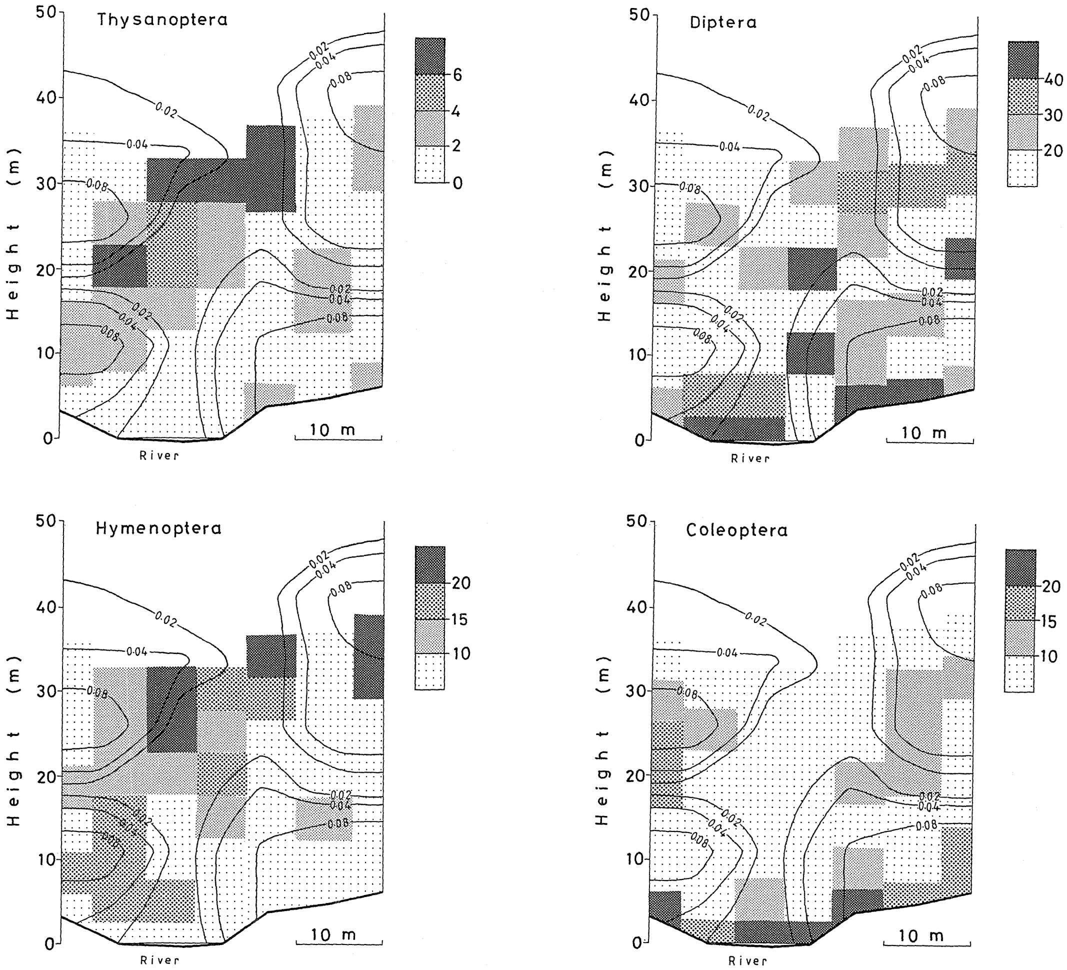

FIGURE 5. Spatial distribution of individual numbers per trap. Background contour lines indicate foliage density distribution (FIGURE 4a).

TABLE 1. Correlation coefficients between environmental factors and per trap individual number of major taxa. The total individual number in each taxon was used in this analysis. Foliage density varies in some orders of magnitude, but logarithms could not be used because foliage density has zero value at some sites. The transformation $x^{1/4}$ was used to consider the effect of low density foliage.

Taxon	Height	Relative light intensity	Foliage density
Thysanoptera	0.4706*	0.5881*	−0.4011*
Hymenoptera	0.4535*	0.5183*	−0.2864**
Hemiptera	0.1687	0.1441	−0.0421
Diptera	−0.3238**	−0.0948	−0.2387†
Coleoptera	−0.4126*	−0.2463†	−0.1573

* $P < 0.01$, ** $P < 0.05$, † $P < 0.1$.

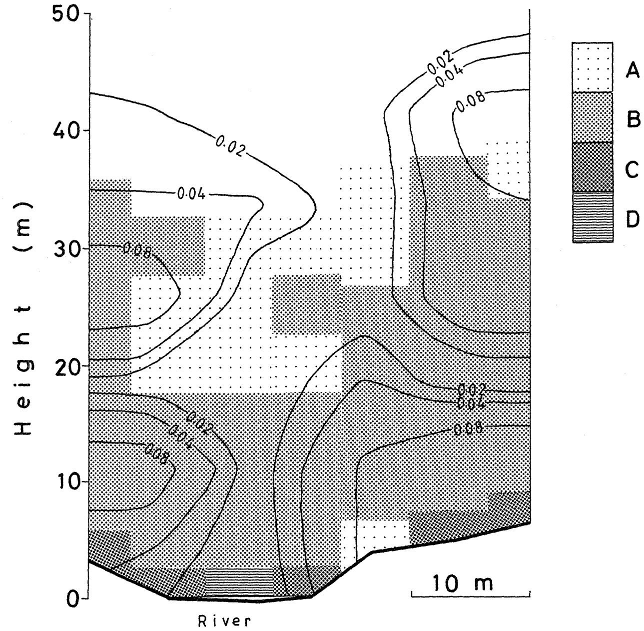

FIGURE 6. Two-dimensional distribution of insect community types, **A** to **D**, in the studied canopy section. Community types were determined by TWINSPAN using order level identification of insect taxa and body size class. Background contour lines indicate foliage density (FIGURE 4a).

extended to the space above the canopy. The representative taxa of Type A community, Thysanoptera and Hymenoptera, showed positive correlation to height and light condition. These results suggest that there may be a Type A community in the space over 40 m.

From studies by Sutton and Hudson (1980), Sutton *et al.* (1983) and Kato *et al.* (1995), general insect distribution patterns determined by light traps in tropical rain forests may show that individual numbers are large at the upper canopy surface, and that a small peak occurs just around the forest floor in some taxa (Kato *et al.* 1995). The results of this study were similar, and no taxon had a maximum abundance within the canopy at intermediate height (Type C, TABLE 2). Some taxa showed differences among sites in the vertical distributions of individual numbers. Coleoptera, for example, were abundant in the upper canopy in many sites (Sutton & Hudson 1980, Sutton *et al.* 1983, Kato *et al.* 1995); but they were abundant also at the forest floor at this site and in two forests in Panama and Brunei (Sutton *et al.* 1983). As shown in this study, small scale canopy structure greatly affects insect distribution. Since quantitative data of the foliage was not available in previous studies, comparison of the results is difficult.

TABLE 2. Average individual number per trap. Insect communities were divided into four types, A to D, with TWINSPAN (Hill 1979).

Taxon	Type A Upper open space (11 sites)	Type B Inside canopy (32 sites)	Type C Forest floor (5 sites)	Type D River surface (1 site)
Thysanoptera	5.5	1.0	1.2	0.0
Hymenoptera	17.6	8.8	5.8	0.0
Hemiptera	6.2	4.4	6.0	2.0
Lepidoptera	0.9	0.3	0.8	0.0
Diptera	29.7	20.0	37.2	154.0
Collembola	0.0	0.2	0.4	0.0
Coleoptera	8.7	8.5	22.4	98.0
Ephemeroptera	0.0	0.1	0.0	30.0
Trichoptera	0.0	0.0	0.0	5.0

Mass collection of migrating insects sometimes occurs, and this affects the absolute individual number (Kato *et al.* 1995). It may also cause fluctuation of the vertical distribution pattern of individual numbers. Community types obtained by TWINSPAN, however, may be more stable than absolute individual number distributions because differences in individual numbers by mass collection were neglected using logarithmic pseudo-species cut levels.

In this study, we used body size, class, and order level identification to distinguish insect communities. Although this classification was rather rough, it is apparent that the different insect communities studied should have different species composition. A given community in this study might contain different compositions in species level identification. The four types of insect communities obtained might be subdivided into more detailed sub-types after species level identification is made.

Flowers of some *Shorea* species belonging to section *Mutuca* (Dipterocarpaceae) are visited by Thysanoptera (Appanah 1990). Tall *Shorea* trees flower usually around Type A areas, where Thysanoptera were abundant. Flowers of trees and shrubs of Annonaceae are often found in the lower layer of tropical rain forests in Southeast Asia (e.g., Whitmore 1990, Momose & Inoue 1994, Koike & Hotta 1996), where Coleoptera were abundant. Some Annonaceae are cauliflorous and some bear flowers only at the base of the trunk. Flowers of lower layer plants including Annonaceae are often visited by Coleoptera (Appanah 1990, Momose & Inoue 1994). Flower position in the canopy might affect pollinator composition to some extent through differences in the background insect community.

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