Effects of Land-Use Changes on Bat Diversity in and around Lambir Hills National Park, Sarawak, Malaysia

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Introduction

Tropical forest landscapes are changing rapidly because of human activities. Approximately half of the potential tropical closed-canopy forest has already been removed and converted to other uses (Wright 2005). The effects of these anthropogenic changes on mammals have been studied across several taxonomic groups. Among these groups, bats (Chiroptera) are thought to be one of the most vulnerable taxa. Major threats to bat populations include the loss or reduction in quality of foraging habitat and habitat fragmentation (Racey and Entwistle 2002).

The order Chiroptera is divided into two suborders: the Megachiroptera, with a single family (Pteropodidae, ca. 163 species) and the Microchiroptera, with 17 families (ca. 814 species in total; Corbet and Hill 1992). Megachiropterans are known as Old World fruit bats and are distributed across Africa, tropical Asia, India, Australia, and their surrounding oceanic islands. Megachiropterans are relatively large (20 - 1500 g) and feed exclusively on plants (fruits, nectar, pollen, flowers, and leaves). In contrast, microchiropterans are found on every continent except Antarctica, are relatively small (1.5 to 150 g), and exhibit more diverse feeding habits (e.g., insectivorous, frugivorous, nectarivorous, ichthyophagous, and sanguivorous; Altringham 1996).

Recent studies have indicated that many bat species play important roles in tropical rain forests. Pollination by bats is a phenomenon restricted to the tropics and subtropics. Megachiropterans visit at least 141 plant species, including a number of commercially important plants (e.g., *Durio, Ceiba,* and *Parkia*) for nectar or pollen (Fujita and Tuttle 1991). Megachiropterans feed upon 145 genera of fruits and presumably disperse the seeds of the majority of the fruits they consume (Marshall 1985). In addition, approximately 70% of extant bat species are insectivorous and prey on a diverse range of insects (e.g., Lepidoptera, Diptera, Coleoptera, and Hemiptera; Jones and Rydell 2002).

Southeast Asia has the highest deforestation rate of any major tropical region, and currently, more than 50% of the land area in Asia is used for agricultural purposes (Zhao et al. 2006). The conversion of forests to cash-crop plantations (e.g., oil palm, rubber, and cocoa) is thought to be one of the major causes of the current high deforestation rates in the region (Primack and Corlett 2005). Such anthropogenic changes can create mosaics of fragmented vegetation, thereby greatly affecting the diversity, abundance, and feeding behavior of bats. Megachiropterans that inhabit these mosaic landscapes are expected to feed on crops because some agricultural plants may serve as food sources, and the bats can fly long distances from mosaic to mosaic. However, little is known about the effects and extent of the impacts of these anthropogenic changes.

The area surrounding a primary forest of the Lambir Hills National Park in Borneo is a typical example of such a mosaic landscape, including various agricultural lands and fragmented primary and secondary forests. In this study, we investigated the bat community in the mosaic landscape. Specifically, we explored differences in the density and diversity of megachiropterans between primary forests and agricultural lands within the landscape.

Methods

We conducted our research in and around the Lambir Hills National Park (LHNP), Sarawak, Malaysia (Fig. 1; 4°2'N, 113°50'E; ca. 150 m a.s.l.). One characteristic of the site was the high heterogeneity of vegetation. We selected four types of vegetation for bat censuses: primary forests, secondary forests, orchards, and oil palm plantations. The primary forests were intact lowland mixed dipterocarp forests within the LHNP. The park covers an area of 6949 ha and the height of emergent trees sometimes exceeds 70 m. Shanahan and Debski (2002) recorded 10 species of bats (five megachiropterans and five microchiropterans) in the park. The secondary forests were young forests that developed after slash-and-burn agriculture had been conducted by Iban villagers. Census points were established in three forests of varying ages: a 7-year-old forest dominated by *Vitex pinnata*, an approximately 30-year-old forest dominated by *Artocarpus elasticus*, and a >60-year-old forest dominated by A. *elasticus* (Nakagawa et al. 2006). Forest height varied among census points (2 - 25 m). These forests were surrounded by ponds, paddy fields, isolated intact forests, and rubber (*Hevea brasiliensis*) forests. The orchards were small (<5 ha) areas with many cultivated plants (e.g., *Durio kutejensis*, *Nephelium lappaceum*, *Carica papaya*, *Cocos* sp., *Musa* sp., *Parkia* sp., *Artocarpus integer*, *Lansium domesticum*, *Piper* sp., and *Saccharum* sp.) established by Iban villagers. Tree height ranged from 1 to 10 m. The orchards were located near villagers' houses and were surrounded by ponds, paddy fields, rubber forests, and bamboo groves. The oil palm plantations were large-scale (ca. 4000 ha) continuous plantations of mature African oil palm (*Elaeis guineensis*) managed either by a corporation or by Iban villagers. Vegetation consisted of a complete monoculture, and the heights of oil palms were 10 to 20 m. The plantations shared borders with the primary and secondary forests.

Censuses were conducted four times between April 2005 and August 2006. We set mist nets on the ground along trails in the forests or forest edges. In the primary forests, we also set nets on canopy walkways (at a height of 15 to 35 m) for five nights. There were no significant differences between data from the ground and the walkways so the data were combined. We used two to four nets (24- to 36-mm mesh; 6 to 12 m long; 6.0 m high; eight shelves) per night and occasionally harp traps (The Austbat Harptrap, Faunatech and Austbat, Australia; 4.2 m2 in area; four nights in the primary forests and two nights in the orchards). Traps were set at sunset and checked at 15-min intervals. Sampling continued until 2300 hours unless it rained, since bat activities are usually very low in the rain. We recorded age, sex, morphological measurements, and reproductive state of the captured bats. Age class was determined by the degree of fusion of the epiphyseal plates on the phalanges, which can be determined without harming the bats (Kunz 1988). Bats with unfused epiphyseal plates were regarded as juveniles. The number of census points and sampling effort varied among vegetation type: 14 179 m2h (area of traps [m2] × sampling time [h]) in the primary forests (six census points), 8707 m2h in the secondary forests (three census points), 6526 m2h in the orchards (three census points), and 3382 m2h in the oil palm plantations (five census points).

We identified bat species according to Payne and Francis (1998). Because some studies have suggested the presence of two cryptic species within *Cynopterus brachyotis* that differ significantly in genetic and morphological characteristics as well as habitat preferences (Francis 1990; Abdullah et al. 2000; Abdullah 2003), we divided the species into two categories (C. *brachyotis* I and C. *brachyotis* II). We classified individuals of C. *brachyotis* based on their forearm length: in adult C. *brachyotis* I (the larger form), the forearm length ranged from 60 to 66 mm, whereas for adult C. *brachyotis* II (the smaller form), the forearm length was approximately 55 mm but always less than 60 mm (M.T. Abdullah, UNIMAS, pers. comm.). If individuals of the species were juveniles and their forearm lengths were less than 60 mm, they were recorded as “C. *brachyotis* (unidentifiable)”.

A chi-squared test (Sokal and Rohlf 1973) was used to compare the number of captures of megachiropterans, microchiropterans, and each individual species among the vegetation types. In the chi-squared tests, the observed and expected numbers of captures were compared. The expected number of captures was calculated based on the assumption that the capture rate was equal for each vegetation type.

Simpson’s index of diversity (Simpson 1949) was calculated for each vegetation type. Unidentifiable individuals of C. *brachyotis* (see above) were assigned to C. *brachyotis* I and C. *brachyotis* II based on the proportion of the two forms in the community.

Results

The total sampling effort (32 795 m2h) resulted in the capture of 495 bats representing 28 species in five families. The capture rate of megachiropterans differed significantly ($P < 0.001$) among the four vegetation types and was particularly high in the oil palm plantations and orchards compared to the primary and secondary forests (Table 1). The capture rate of microchiropterans also differed significantly ($P < 0.001$) among vegetation types and was lower in the oil palm plantations compared to the other three plant communities (Table 1).

For the eight bat species with relatively large sample sizes (>20 individuals), capture rate varied among vegetation types (Table 1). The capture rates of *Balionycteris maculata*, *Penthetor lucasii*, and *Hipposideros cervinus* were the highest in primary forests. Capture rates were lower in secondary forests than in primary forests for all species except *C. brachyotis* I and II. In the orchards, the capture rates of *Eonycteris spelaea*, *Macroglossus minimus*, and *Glischropus tylopus* were very high compared to those in the other three vegetation types. In contrast, *B. maculata* and *P. lucasii* were not observed in the orchards. In the oil palm plantations, the capture rate of *C. brachyotis* I was notably higher than in the other vegetation types. However, the capture rates of other bat species were low or zero in the plantations.

Cynopterus brachyotis I was the most common and abundant species in all vegetation types, except for primary forests. This species accounted for 44% of all bats in the secondary forests, 41% in the orchards, and 72% in the oil palm plantations. In the primary forests, the dominant species was *H. cervinus* (24% of all bats), and *C. brachyotis* I accounted for only 4% of bats.

Simpson’s index of diversity also varied among plant communities (Table 2). Simpson’s index for megachiropterans was highest in primary forests, lower in secondary forests and orchards, and lowest in the oil palm plantations.

Discussion

To our knowledge, ours is the first study to demonstrate clear differences in the diversity and abundance of bats among forests and agricultural lands within a single landscape in Southeast Asia. The study showed that the diversity and abundance of bats are strikingly different among different vegetations in spite of a relatively small study area. In addition, the observed movements and feeding habits demonstrated potential effects of agricultural lands on nearby forests or other vegetation.

Relative to primary and secondary forests, the number of megachiropteran species was somewhat low in orchards and notably low in the oil palm plantations. In addition, the capture rates of two frugivorous bats (*B. maculata* and *P. lucasii*) clearly differed among the four vegetation types, and the two species were not recorded in the orchards or the oil palm plantations. These results indicate that megachiropteran species rarely use agricultural lands for feeding; thus, the vegetation is not suitable for maintaining a diversity of megachiropterans. Moreover, there may be no species unique to agricultural lands because those species for which more than two individuals were captured were also recorded at least once in the primary or secondary forests. Megachiropteran diversity in natural forests is thought to be maintained by various factors, including the diversity of food sources (Hall et al. 2004; Hodgkison et al. 2004a), the availability of roosts for tree-roosting bats (Zubaid 1993), and the heterogeneity of forest structure (Hall et al. 2004; Hodgkison et al. 2004b). The oil palm plantations clearly lacked these characteristics.

The capture rate of megachiropterans differed significantly among vegetation types, with high rates in the oil palm plantations and orchards and low rates in the secondary and primary forests. This trend was nearly opposite to the pattern of bat diversity; diversity was quite low in plantations, low in orchards and relatively high in the secondary and primary forests. The observed high capture rate and low species diversity of megachiropterans in agricultural lands were similar to the pattern reported by Hall et al. (2004), although their sampling sites were scattered across Southeast Asia and the crop species studied differed from those in our study. In the Philippines, Heaney et al. (1989) also measured high capture rates and low diversity of megachiropterans in agricultural lands relative to lowland forests. Thus, these patterns may be common throughout Southeast Asia. Similar patterns have also been found in the Neotropics. For example, Medellin et al. (2000) observed both low species richness of phyllostomid bats and high dominance of particular bat species in agricultural lands (shaded cacao plantations and cornfields with other crops) compared to adjacent rainforests. Phyllostomid bat diversity was also low in coffee plantations relative to small fragmented forests (Numa et al. 2005).

Microchiropterans showed a pattern quite different from megachiropterans. The capture rate of microchiropterans was lower in the oil palm plantations but did not differ among the other three vegetation types. One possible cause of the strikingly low capture rate of microchiropterans in the oil palm plantations may have been the low abundance of insects. Although studies concerning the abundance of prey insects in this vegetation type are rare, Chung et al. (2000) reported low beetle abundance and diversity in oil palm plantations compared to logged and primary forests in Sabah, Malaysia.

The drastic increase of *C. brachyotis* I in the oil palm plantations was a particularly intriguing result. The population size of *C. brachyotis* I in the oil palm plantations may indeed be large, considering that its capture rate was extraordinarily high and the plantations cover a vast area (ca. 388,500 ha in Sarawak as of 2004; Brown and Jacobson 2005). High capture rates and dominance of *C. brachyotis* in agricultural lands have been reported repeatedly in other regions (Abdullah et al. 1997; Hall et al. 2004). For example, Abdullah et al. (1997) measured a very high capture rate of *C. brachyotis* (570 individuals per 10,000 m^2h) in *Cocos* and *Musa* plantations in Indonesia, where *C. brachyotis* accounted for 93% of total captures. We collected seeds of forest plants from individuals captured in the plantation. The results indicate that the species move into, and affect, adjacent forests, although the intensity of the effects is unknown.

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Table 1 Capture rate of bats (individuals per 10,000m2h). Data for species with small sample sizes (<20 individuals) are not shown. The rightmost column presents results of the Chi-squared test: *P < 0.05, **P < 0.01, ***P < 0.001, –: impossible to test due to small sample size.

	Primary forests	Secondary forests	Orchards	Oil palm plantations	Significance
Megachiropterans	55	86	208	272	***
Microchiropterans	40	26	49	6	**
Each species					
Megachiroptera					
Balionycteris maculata	16	2	0	0	-
Cynopterus brachyotis I	4	49	106	201	***
C. brachyotis II	8	11	6	9	-
Eonycteris spelaea	4	1	44	12	***
Macroglossus minimus	5	3	31	0	***
Penthetor lucasii	13	3	0	0	-
Microchiroptera					
Hipposideros cervinus	23	13	11	3	*
Glischropus tylopus	4	1	31	0	-

Table 2 Simpson's index of diversity in the four vegetation types. (N: number of individuals, S: number of species, 1/D: Simpson's index of diversity). 1/D was not calculated for microchiropterans in oil palm plantations due to the small sample size.

		Primary forests	Secondary forests	Orchards	Oil palm plantations
Megachiropterans	*N*	78	75	136	92
	S	8	10	6	3
	1/*D*	5.00	2.09	2.54	1.19
Microchiropterans	*N*	57	23	32	2
	S	11	8	5	2
	1/*D*	2.95	3.50	2.24	
All bats	*N*	135	98	168	94
	S	19	18	11	5
	1/D	7.86	3.38	3.65	1.24

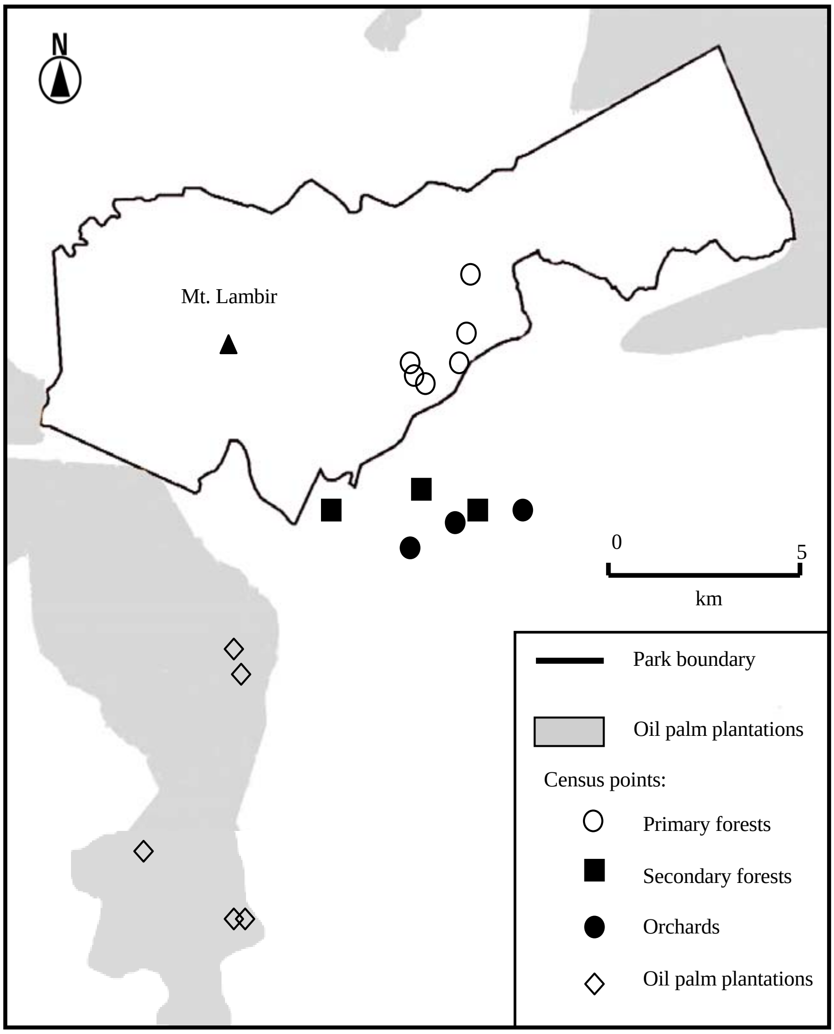

Figure 1. Study area and location of census points.