

## Effect of Forest Use on Community Structures and Trophic Levels of Small Mammals in Sarawak, Malaysia

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### Introduction

In terrestrial forest ecosystems, anthropogenic effects on biodiversity and ecosystem function are a global concern. Tropical rain forests in Southeast Asia are characterized by extremely high plant diversity (Whitmore 1984); however, these forests have been exposed to drastic and rapid deforestation because of an increasing human population and a developing economy. The effect of altering habitats in tropical forests on the biodiversity of wild animals is an urgent subject for species conservation and proper forest management. Much research has been conducted on the effects of deforestation or forest use on changes in wildlife species composition or abundance, such as that for logged forests (Willott et al. 2000), fragmented forests (Harrington et al. 2001), and fallows (Medellín and Equihua 1998). In reality, however, a landscape is a complex assemblage of these forest types. To clearly understand the effects of forest use on the community structure in a region, we must assess a complex assemblage of these diverse vegetation types. The alternation of plant species composition and tree size in degraded forests may also be accompanied by changes in food resource availability for wild animals, resulting in changes in their food intake (Panasci and Whitacre 2000). The analysis of stable nitrogen isotopes ( $\delta^{15}\text{N}$ ) in organisms is a powerful tool with which to investigate trophic positions within a food web.

Our objective was to analyze the distribution patterns and levels of  $\delta^{15}\text{N}$  in small mammals in fragmented primeval forests, abandoned fallows at three different developmental stages, and rubber plantations, as compared with the distribution patterns and  $\delta^{15}\text{N}$  levels in primary forests to determine the effects of human forest use on small mammal communities and trophic levels in Sarawak, Malaysia. Because small mammals play an important role as seed dispersers in forest ecosystems and form the base of the mammalian food chain (Shine et al. 1998; Shanahan and Compton 2000), understanding the effects of forest uses on small mammals is needed to determine proper forest management strategies.

### Materials and Methods

#### *Study site*

A field survey was conducted during August–September 2003, June – July 2004, and January–March 2005 in and around Lambir Hills National Park (LHNP), Sarawak, Malaysia (4°2'N, 113°5'E). The study site contained 20 plots (each 10×100 to 10×200 m) in six forest types: primary forests (two plots), fragmented primeval forests (six plots), abandoned fallows at three different developmental stages (new, young, and old: three plots each), and rubber plantation (three plots). Light conditions on the forest floor were determined by

quantifying the percent canopy openness using a digital camera with a fisheye lens (Cool Pix 910, Nikon).

#### ***Small mammal trapping and litter sampling***

Small mammals were live-trapped for five consecutive days and nights using wire-mesh live cage traps (15×12×30 cm). One trapping series was conducted in each study plot during each field survey for a total of three trapping series. Traps were baited with banana and sweet potato and covered with a sheet of transparent plastic to exclude rainfall. We checked all traps once a day in the morning (0700–1100 hours). Captured individuals were identified according to Payne et al. (1985) and marked by toe clipping with a unique number at the site of capture. After marking and recording sex, weight, reproductive condition, and capture point, individuals were released. Nomenclature follows that of Payne et al. (1985). The clipped toes were immediately returned to the laboratory, stored in a freezer at –20°C, oven-dried at 50°C for 48 h, and kept dry until analysis.

Leaf litter samples were hand-collected from ten 15×15 cm quadrats at 10-m intervals within each plot. These were oven-dried at 50°C for 72 h and ground to fine powder after removing sand and fungi from the leaves, twigs, and petioles.

#### ***Isotope analysis***

For the  $\delta^{15}\text{N}$  analysis, samples from 144 individuals, representing 19 species in 3 families (treeshrews, squirrels, and rats or mice) were folded into tin capsules. The level of  $\delta^{15}\text{N}$  was measured using a mass spectrometer (Delta S or Delta plus XP, Germany) coupled with an Elemental Analyzer (Flash EA 111). The natural abundance of  $^{15}\text{N}$  is expressed in per mil (‰) deviation from an international standard:  $\delta^{15}\text{N} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000$ , where  $R$  is  $^{15}\text{N}/^{14}\text{N}$ . Atmospheric N was used as the N standard.

#### ***Data analysis***

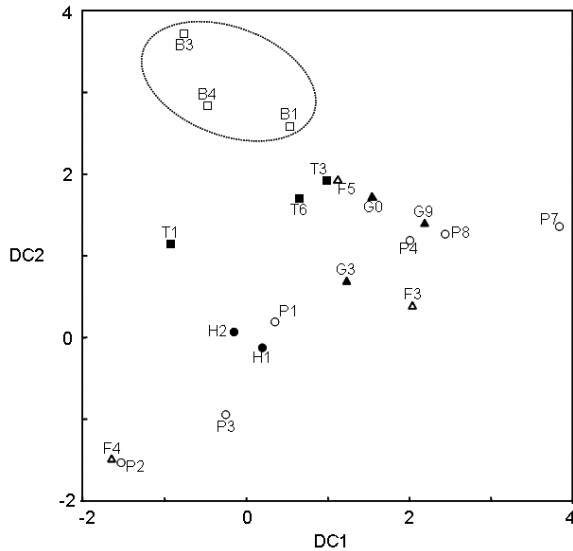
We conducted detrended correspondence analysis (DCA) on the species abundance data ( $N \geq 5$ ) to identify gradients in the small-mammal assemblages over the 20 study plots. Less common species ( $N$  of captures  $< 5$ ) were excluded from the DCA. To correct for differences in the  $\delta^{15}\text{N}$  of primary production among sites, we calculated the average  $\delta^{15}\text{N}$  of 10 leaf litter samples from each plot and estimated the corrected  $\delta^{15}\text{N}$  of small mammals as:  $\delta^{15}\text{N}_{\text{corrected}} = \delta^{15}\text{N}_{\text{small mammal}} - \delta^{15}\text{N}_{\text{leaf litter}}$ , where  $\delta^{15}\text{N}_{\text{small mammal}}$  is the directly measured  $\delta^{15}\text{N}$  of a small mammal at a particular site and  $\delta^{15}\text{N}_{\text{leaf litter}}$  is the average  $\delta^{15}\text{N}$  of 10 leaf litter samples from that plot. DCA was performed using CANOCO 4 (ter Braak and Smilauer 1998) and all other statistical analyses were performed using JMP 4.0 (SAS Institute 2000).

## **Results**

### ***Community structures of small mammals***

In total, we captured 283 individuals of 22 species from four families: Tupaiidae, Muridae, Sciuridae, and Erinaceidae. DCA extracted two axes that cumulatively accounted for 45.7% of the variation in the small mammal species abundance data. The first axis (DC1) was significantly correlated with the abundance of *Niviventer cremoriventer*, *Sundamys muelleri*, and *Leopoldamys sabanus*, whereas the second axis (DC2)

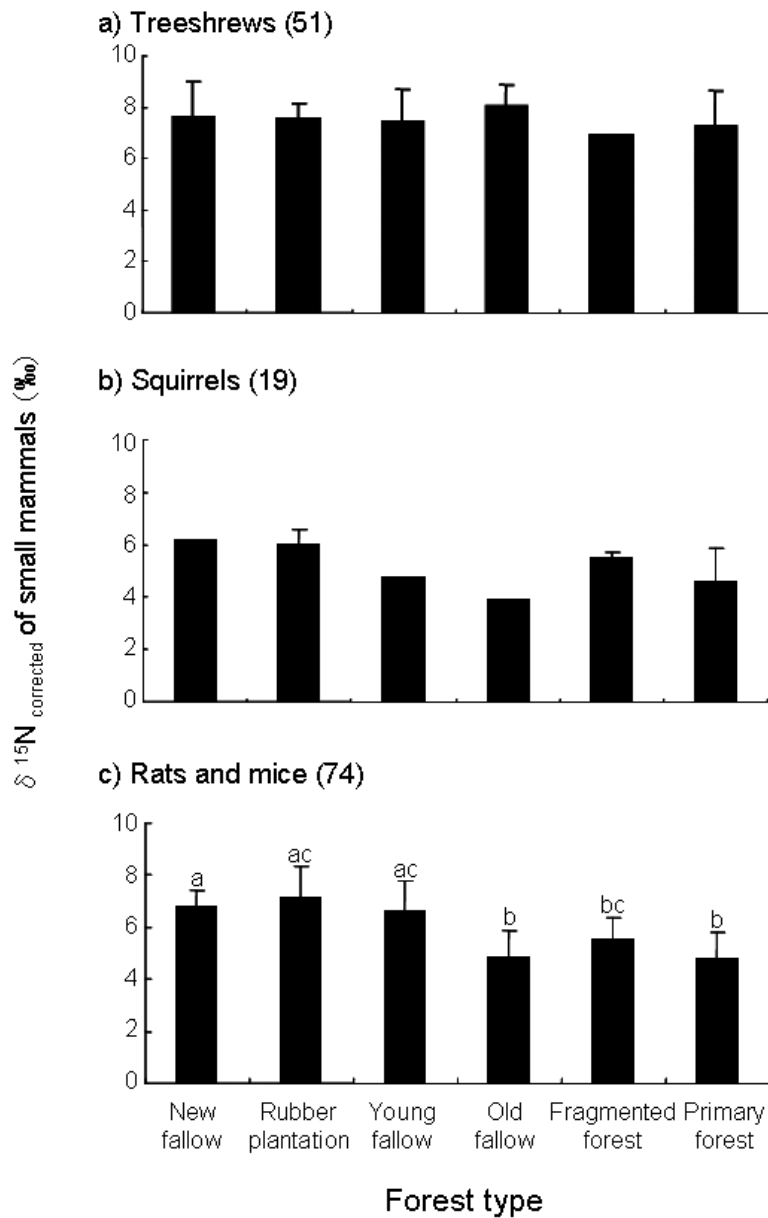
was significantly correlated with the abundance of *Tupaia minor*, *T. gracilis*, and *Rattus rattus*; both correlations were positive. DC2 was also significantly negatively correlated with the abundance of *Maxomys rajah*. The DCA showed two distinctive groups: new fallow and other forest types (Fig. 1). The three new fallow plots had a high abundance of two species of treeshrew and house rat (*R. rattus*). However, there was no obvious partitioning among the other five forest types.



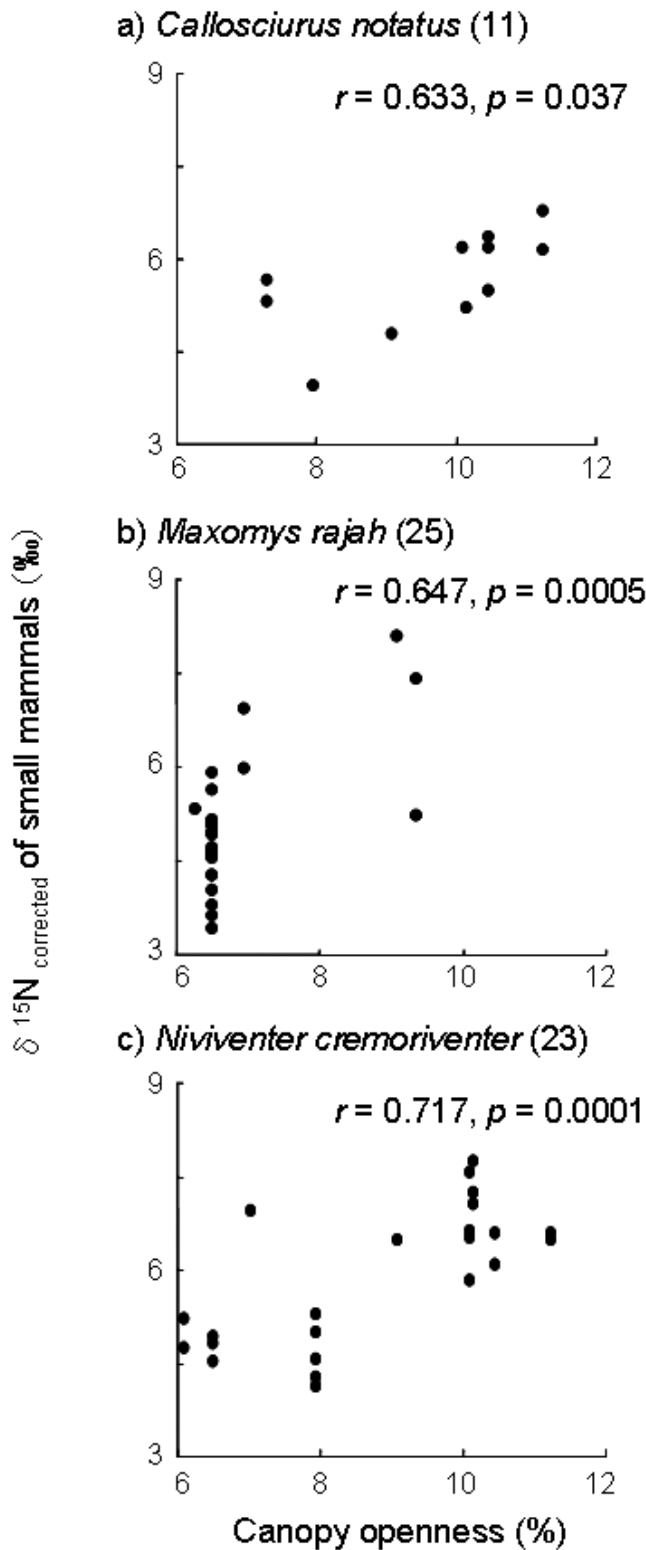
**Fig. 1** Plot of the first two axes of the detrended correspondence analysis of the small mammal community species-abundance data ( $N \geq 5$ ) from 20 study plots. Symbols indicate the forest type: solid circle, primary forest; open circle, fragmented primeval forest; solid square, young fallow; open square, new fallow; solid triangle, rubber plantation; and open triangle, old fallow; after Nakagawa et al. (2006).

### ***Trophic levels of small mammals***

Differences in the  $\delta^{15}\text{N}$  of leaf litter among the forest types were small and not significant. The  $\delta^{15}\text{N}_{\text{corrected}}$  of rats and mice differed significantly among forest types (ANOVA,  $F = 10.83$ ,  $P < 0.0001$ ); those in forests that had been used relatively recently, such as new and young fallow and rubber plantations, had significantly higher levels of  $\delta^{15}\text{N}_{\text{corrected}}$  than did those in primary or fragmented forests and old fallow (Fig. 2). In contrast, we found no significant differences in levels of  $\delta^{15}\text{N}_{\text{corrected}}$  for treeshrews and squirrels among forest types. Canopy openness differed significantly among forest types (ANOVA,  $F = 8.32$ ,  $P < 0.001$ ) and was highest in new fallow. For the squirrel *Callosciurus notatus* and two rat species, *M. rajah* and *N. cremoriventer*, canopy openness and  $\delta^{15}\text{N}_{\text{corrected}}$  were significantly and positively correlated (Fig. 3); such a pattern was not found for lesser (*T. minor*) or large (*T. tana*) treeshrews.



**Fig. 2**  $\delta^{15}\text{N}_{\text{corrected}}$  of (a) treeshrews, (b) squirrels, and (c) rats and mice among six forest types. Bars sharing any letters are not significantly different among the forest types (Scheffe's multiple comparison,  $P < 0.05$ ). No significant differences were detected in treeshrews and squirrels. Sample sizes are indicated in parentheses; after Nakagawa et al. (2007).



**Fig.3** Correlations between canopy openness and the  $\delta^{15}\text{N}_{\text{corrected}}$  of (a) *Callosciurus notatus*, (b) *Maxomys rajah*, and (c) *Niviventer cremoriventer*. Sample sizes are shown in parentheses; after Nakagawa et al. (2007).

## Discussion

The analysis of small mammal species abundance among forest types indicated two distinct groups. Small

mammal communities in new fallow had comparatively more house rats and lesser and slender treeshrews. The house rat is a human-associated species that is adapted to disturbance (Lynam and Billick 1999). The high occurrence of rats in new fallow, where disturbance had recently occurred and recovery from the disturbance had not yet advanced, is not unexpected. Lesser and slender treeshrews occur in gardens and plantations, as well as in forests (Payne et al. 1985), suggesting that they could be adaptable to disturbed habitats. Our results also indicate that small mammal communities could recover from the disturbance relatively quickly, that is, within several years after slash-and-burn agriculture. Although the species composition of young fallow was not entirely similar to that of primary forest, the plots in young fallow were included in the same group as primary forest; moreover, these plots contained some interior forest specialists or dominant species in the primary forest, such as Muller's rat and brown spiny rat, which showed significant correlations with the DCA axes.

Rats and mice in highly degraded forests (e.g., new and young fallow and rubber plantation) were more enriched in  $^{15}\text{N}$  compared to those in primary forests or somewhat degraded forests (e.g., old fallow and fragmented primeval forest). This result indicates that rats and mice in highly degraded forest are likely to feed on more consumers such as invertebrates rather than on plant organs compared with rodents in primary or somewhat degraded forests. On the other hand, the  $\delta^{15}\text{N}$  of treeshrews did not differ among forest types, suggesting that their diet was not affected by forest uses. This result indicates that treeshrews that normally prefer to consume insects may be less affected by insect abundance as a result of changes in forest uses. The trend was also supported at the species level, except for treeshrews. Two species of rat and one species of squirrel showed significantly higher  $\delta^{15}\text{N}$  in forests with high compared to low canopy openness, suggesting an increase in consumers in their diets. In disturbed forests, which have high canopy openness, insects such as flies and butterflies were abundant (Willott et al. 2000; Horn et al. 2005). Rats and mice in the region are thought to consume a wide range of fruits or seeds, as well as insects (Payne et al. 1985; Kitamura et al. 2006). When insects are abundant, they may be easy to capture as a food resource. Direct quantification of diet or gut contents analysis of small mammals in a future study would clearly support our hypothesis.

Given the variation in the food supply and changes in vegetation cover that accompany habitat disturbances, dietary flexibility would be crucial for survival in degraded forests. The dietary flexibility of rats and squirrels may be the reason why community structures of small mammals are similar among various forest types examined in this study (except for new fallow). However, changes in the feeding activity of small mammals associated with forest uses may affect the distribution or survival of insects through higher predation pressure, as well as the regenerating patterns of plants through decreased predation and dispersal of fruits.

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