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PHYTOPHAGOUS SCARABAEID DIVERSITY IN SWIDDEN CULTIVATION LANDSCAPES IN SARAWAK, MALAYSIA

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ABSTRACT. **–** In Southeast Asia, swidden cultivation is one of the most important land uses, as it forms and maintains complex mosaics of fallows at various stages in the area. To understand the roles of such a mosaic landscape for biodiversity conservation, we compared the species diversity of phytophagous scarabaeids collected by light trapping among 20 study plots in the following six forest types in Sarawak, Malaysia: primary forest, isolated primary forests, rubber gardens, old fallows, young fallows, and new fallows. Estimated species richness did not significantly differ among the forest types. In contrast, evenness values of new fallows were remarkably lower than those of the other forest types. In addition, species composition could be classified into two groups: new fallows and other forests. These results suggest that rubber gardens and fallows at various stages, with the exception of new fallows, tend to maintain phytophagous scarabaeid diversity at the level found in primary forests or at least in isolated primary forests. These findings highlight the roles of complex mosaic landscapes composed of primary forests and fallows formed in the process of swidden cultivation in recovering and maintaining phytophagous scarabaeid diversity in Southeast Asian tropical landscapes.

KEY WORDS. **–** fallow, Lambir Hills National Park, land use, SE Asian tropics, Scarabaeidae, slash-and-burn agriculture.

INTRODUCTION

In Southeast Asia, swidden cultivation is one of the most important land uses (Mertz et al., 2009; Padoch & Pinedo-Vasquez, 2010), as it forms and maintains complex mosaics of tropical forests and fallows at various stages of plant regrowth (Mertz et al., 2009; Rerkasem et al., 2009; Padoch & Pinedo-Vasquez, 2010). Fallows, which are secondary forests that form during the resting period of swidden cultivation, are an important component of landscapes in tropical forest areas, particularly in light of biodiversity conservation and the livelihood of local people (Padoch & Pinedo-Vasquez, 2010). For example, fallows contribute to the reduction of weeds and pests, promote fertility restoration, and provide valuable resources for human use (Szott et al., 1999; Ichikawa, 2004). Fallows also function as corridors and habitats for animals (Bowman et al., 1990; Mathieu et al., 2005). However, the roles of forests modified by swidden cultivation in biodiversity conservation remain unexplored due to the lack of sufficient empirical data.

The landscape surrounding the preserved primary forests of the Bakon River basin in Sarawak, Malaysia, is composed of swidden fields, fallows in various stages, rubber gardens, and isolated primary forests (Ichikawa, 2004). The local people (the Iban) have collected and used forest resources in the fallows without management for at least 7–10 years (Ichikawa, 2004). The fallows are also used as rubber gardens; i.e., rubber trees have been planted in the fallows to produce crude rubber as a cash crop (Ichikawa, 2004). Today, however, most of the rubber gardens have been abandoned for these purposes (Ichikawa, 2004). Isolated primary forests are also important components of the Sarawak landscape. These forests are primarily located on ridges, and the local people selectively cut the trees within these forests for the construction of houses or coffins (Nakagawa et al., 2006). The conversion of swidden lands to other uses such as monocrop plantations is currently increasing in the area (Ichikawa, 2007; Schmidt-Vogt et al., 2009), and this process is a threat to habitats of plants and animals (Fitzherbert et al., 2008; Koh & Wilcove, 2008; Brühl & Eltz, 2010). Therefore, evaluating the animal and plant species diversity in swidden lands is crucial for creating policies concerning biodiversity conservation and proper forest management in the region.

To date, several studies have investigated the effects of forest use, including swidden cultivation, on the biodiversity and microenvironmental conditions around Lambir Hills National Park in Sarawak. For example, Nakagawa et al. (2006) found remarkable differences in characteristics such as canopy openness, tree-species richness, and tree density among forest types (fallows with varying time since the end of cultivation, rubber gardens, isolated primary forests, and preserved primary forests). In addition, the species diversity and composition of plants (Momose et al., unpublished), small mammals such as tree shrews and rodents (Nakagawa et al., 2006), bats (Fukuda et al., 2009), ants (Tanaka et al., 2007; Matsumoto et al., 2009), butterflies (Itioka et al., unpublished), and macrofungi (Yamashita et al., 2008) have been shown to differ among these forest types. Most studies have indicated that species diversity was highest in preserved primary forests. However, the patterns of variation in diversity among forest types differed among taxonomic groups. Similar phenomena have been reported in Amazonian (Gascon et al., 1999; Mathieu et al., 2005; Barlow et al., 2007) and central African landscapes (Basset et al., 2008). Therefore, to better understand the total contribution of swidden landscapes, i.e., landscapes affected by swidden cultivation, to biodiversity conservation, the species diversity and community structure of the various components of swidden landscapes must be evaluated for various taxonomic groups.

In this study, we targeted phytophagous scarab beetles (Melolonthinae, Rutelinae, Dynastinae, and Cetoniinae) in a swidden landscape in Sarawak. This taxonomic group serves as a useful indicator for measuring species diversity, as these beetles can be easily collected quantitatively by light trapping due to their nocturnal flying activities (e.g., Lawrence & Britton, 1994). In addition, their food habits are generally well known: adults tend to feed on flowers, leaves, fruits, and tree sap, whereas larvae feed on plant roots under the ground and rotten wood (e.g., Hill, 1983; Lawrence & Britton, 1994). Thus, these species are expected to be susceptible to changes in the environmental conditions of their microhabitats such as changes in forest type affected by swidden cultivation. At the study site, six forest types (new fallows, young fallows, old fallows, rubber gardens, isolated primary forests, and preserved primary forests) were classified into three habitat groups according to microenvironmental conditions, following the classification of Nakagawa et al. (2006): primary forests (Group 1), new fallows (Group 2), and other forests (Group 3). We postulated that scarabaeid diversity (measured by three indices: estimated species richness, evenness, and species composition) would differ among these habitat groups, with highest index values in forests of Group 1 and lowest values in forests of Group 2. To address this postulate, we performed a field study that compared diversity values among these three habitat groups.

MATERIAL AND METHODS

Study site

A field survey was conducted from 11 Aug 2 – Oct.2003 in and around Lambir Hills National Park (LHNP), Sarawak, Malaysia (4°2'N, 113°50'E, 150–200 m asl; Fig.1). The mean annual temperature at LHNP is ca. 27°C (Kumagai et al., 2009), and the monthly temperature varies less than 2°C (Harrison, 2005). The mean annual rainfall in LHNP for the period of 2000–2006 was around 2600 mm (Kumagai et al., 2009), and there is no clear dry season (Nakagawa et al., 2000). LHNP covers an area of about 6949 ha, which is mainly covered by primary forest dominated by dipterocarp trees (Yumoto & Nakashizuka, 2005). Around the park, local people (the Iban) have traditionally cultivated fields of rice and vegetables using slash-and-burn agriculture (Ichikawa, 2004).

Around LHNP, we selected three forest stands as study plots in each of the following forest types (Fig. 1): new fallows (B3, B4, B5), young fallows (T1, T4, T6), old fallows (F3, F4, F5), and rubber gardens (G0, G3, G9) as well as five stands in isolated primary forests (P1, P2, P3, P4, P7). In addition, we established three stands in the preserved primary forest in LHNP (H1, H2, H3); the H1 and H3 plots were located in the Canopy Biology Plot, and the H2 plot was located in the Crane Plot (Fig. 1; see Yumoto & Nakashizuka (2005) for details on the two plots). The average distance between our study plots was about 2860 m (range: 42–5842 m). The isolated primary forests in which we established the study plots were patchily distributed around LHNP and were dominated by *Dryobalanops aromatica* (Dipterocarpaceae) (Nakagawa et al., 2006). The areas of these forests ranged from 0.3 to 5.0 ha (Nakagawa et al., 2006). These isolated forests are not primary forests in the strict sense because the local people sometimes selectively cut trees for the construction of houses or coffins (Nakagawa et al., 2006). However, the average tree height and canopy structure within these forests are similar to those of the primary forest. Hence, we herein refer to these isolated forests as isolated primary forests.

Since the 1950s, the local people have planted rubber trees (*Hevea brasiliensis*, Euphorbiaceae) as a cash crop in some of the fallows (Ichikawa, 2004). Based on the number of years since the abandonment of swidden cultivation, we categorised the fallows into three forest types: old fallows

(>20 years), young fallows (5–6 years), and new fallows (1 year). Young and old fallows were dominated by *Vitex pinnata* (Vervenaceae) and *Artocarpus elasticus* (Moraceae), respectively (Nakagawa et al., 2006). In new fallows, the vegetation was dense with Cyperaceae grasses, mixed with small pioneer trees (Nakagawa et al., 2006).

The classification by Nakagawa et al. (2006) of the six main forest types into three habitat groups was based on characteristics of spatial structure such as canopy openness, tree basal area, tree density, tree species richness, distance to primary forest, and secondary forest area within 600 m (Table 1): plots in the preserved primary forest (Group1) were characterised by large, dense trees with high tree species richness; the plots in new fallows (Group 2) exhibited high canopy openness; and the plots in the other four forest types (Group 3) had larger and more densely distributed trees as well as higher tree species richness compared with Group 2, but they were not surrounded by primary forests. The forest types of Group 3 did not exhibit any obvious differences in spatial structure (Nakagawa et al., 2006). Due to the lack of detailed information on the spatial characteristics of two of our study plots (H3 and T4), their spatial characteristics are not statistically analysed. However, the spatial characteristics of H3 and T4 appear to be similar to those in the other plots in the preserved primary forest and young fallows, respectively.

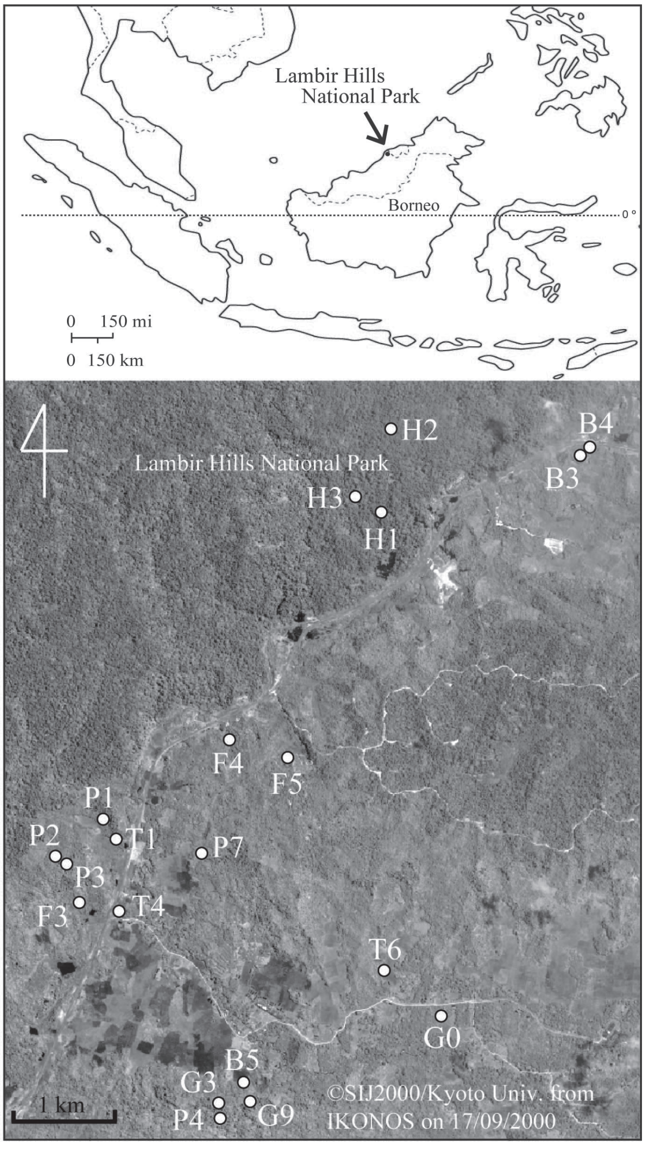

Fig. 1. Satellite image (from IKONOS, 17 Sep.2000 [©SIJ2000/Kyoto University]) of all the study plots in and around Lambir Hills National Park in Sarawak, Malaysia. The letters H, P, G, F, T, and B indicate the following forest types, respectively: preserved primary forests, isolated primary forests, rubber gardens, old fallows, young fallows, and new fallows.

Insect collections

Light traps are useful for collecting nocturnally flying insects. We used Pennsylvania-style light traps, each equipped with a 8-W fluorescent tube for collecting insects with near ultraviolet radiation, two cross boards for intercepting light-attracted flying insects, a funnel and bucket to receive fallen insects, and electric power supplied by a 12-V lead acid battery (Fig. 2). To kill the flying insects, we inserted pieces of paper impregnated with ethyl acetate into the collecting bucket. The light traps were portable and modified for rainforest use following Nakashizuka & Stork (2002). In each plot, we conducted light trapping thrice (three nights) at intervals of at least 7 days over the study period. Three light traps were set simultaneously on the forest floor at intervals of approximately 50 m. The traps were deployed one night (1700 to 0700 hours) in the forest core of each plot.

Target species

Light-attracted scarabaeids (Melolonthinae, Rutelinae, Dynastinae, and Cetoniinae) were sorted into morpho-species based on morphological characteristics using a reference collection of specimens identified by H. Kobayashi, T. Matsumoto, S. Nagai, and K. Wada (Table 2). The specimens were kept at the Forest Research Centre of Sarawak in Kuching.

We excluded several *Maladera* and *Neoserica* (Melolonthinae) species from our analyses due to sorting difficulties. These specimens represented about 6% of the total number of individuals collected during the study period.

Analysis

For analyses, we combined the data for specimens collected in the three light traps during the three nights into one data set for each plot. We compared estimated species richness (Chao1) and community evenness among forest groups using Kruskal–Wallis rank sum tests. We calculated Chao1 richness estimates using EstimateS ver. 8.2 (Colwell, 2009). Community evenness, i.e., the evenness of species' abundance distributions, was evaluated using the Shannon evenness measure (E), where E = Shannon index/ln S (Magurran, 2004). To obtain Shannon indices, we used values of the Shannon mean calculated using EstimateS ver. 8.2 (Colwell, 2009).

Table1. Three habitat groups and their component forest types.

Habitat groups	Forest type	Study plot	Dominant tree species
Group 1	Primary forest	H1 H2 H3	Dipterocarp trees
Group 2	New fallow (1 year)	B3 B4 B5	
Group 3	Young fallow (5–6 years)	T1 T4 T6	*Vitex pinnata*
	Old fallow (>20 years)	F3 F4 F5	*Artocarpus elasticus*
	Rubber garden	G0 G3 G9	*Hevea brasiliensis*
	Isolated primary forest	P1 P2 P3 P4 P7	*Dryobalanops aromatica*

To summarise differences in beetle community structure among forest types, we ordinated the data by nonmetric multidimensional scaling (NMDS) using R statistical software. NMDS was performed with community ecology packages MASS and VEGAN (Oksanen, 2010). Both R and its derivative packages are freely available at http://cran.r-project.org/. In the VEGAN package, we used the function "vegdist" for calculating (Bray-Curtis) dissimilarity (Oksanen, 2010). Using a matrix of dissimilarities, we performed NMDS with function "isoMDS" in the MASS package (Oksanen, 2010).

RESULTS

In total, 3230 individuals of at least 51 morpho-species belonging to four subfamilies of Scarabaeidea were collected throughout the study period (Table 2): Melolonthinae (30 species), Rutelinae (14), Dynastinae (six) and Cetoniinae (one).

Total species richness was highest in isolated primary forests, followed by old fallows, rubber gardens, young fallows, new fallows, and primary forests (Table 2). Total abundance was highest in new fallows, followed by isolated primary forests, rubber gardens, old fallows, young fallows, and preserved primary forests (Table 2).

Estimated species richness (Chao 1) did not differ significantly among forest types (Kruskal–Wallis rank sum test, $\chi^2 = 4.6222$, $df = 5$, $p = 0.4637$; Fig. 3a), but evenness values did (Kruskal–Wallis rank sum test, $\chi^2 = 11.4762$, $df = 5$, $p < 0.05$; Fig. 3b). The evenness values of new fallows were lower than those of the other forest types (Fig. 3b), likely because one species of the genus *Apogonia* tended to dominate or exhibit high abundance in the new fallows (Table 2).

Visual inspection of the NMDS ordination plot of the beetle community indicated that the species composition in Habitat Groups 1 and 3 formed a single group, whereas species composition in Habitat Group 2 formed another

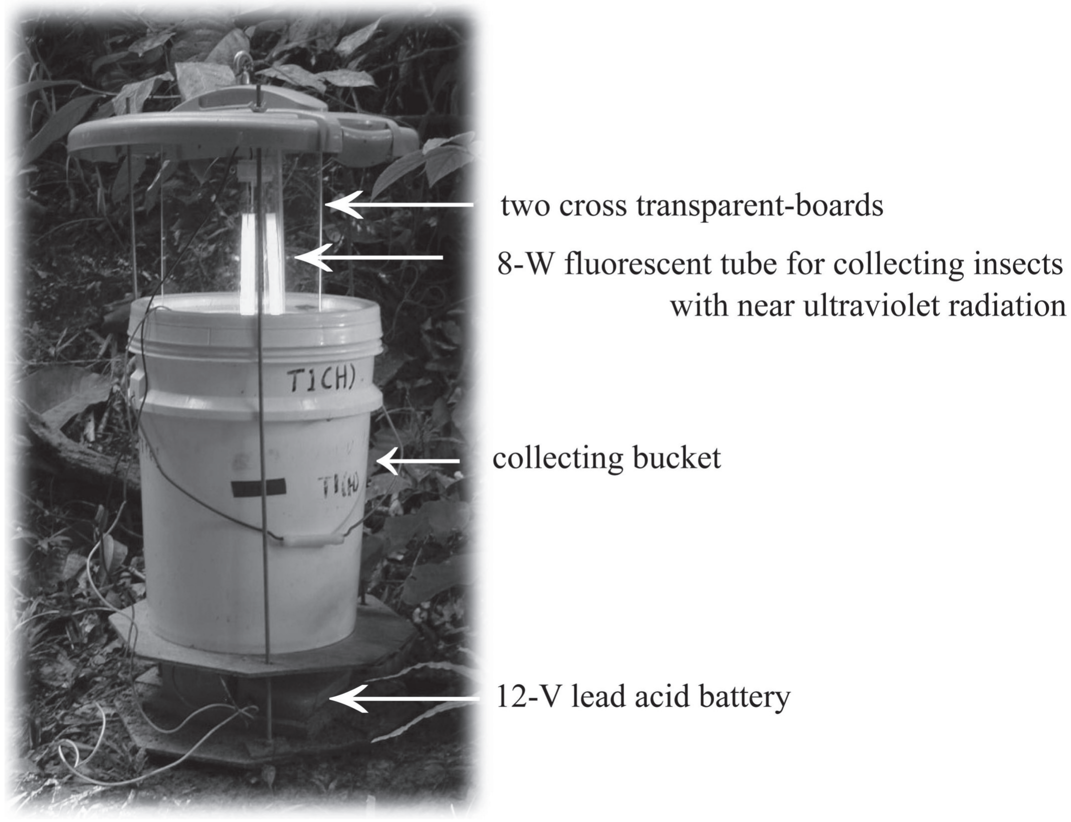

Fig. 2. Image of our light trap.

Table 2. Numbers of each species recorded within each forest type. Small letters indicate the researcher who identified the species: a) H. Kobayashi; b) T. Matsumoto; c) T. Itioka; d) K. Wada; e) S. Nagai.

Species	Forest Type						
	Primary forest	Isolated primary forest	Rubber garden	Old fallow	Young fallow	New fallow	Total
Melolonthinae							
Diplotaxini							
a *Apogonia armadillo* Arrow, 1938		2					2
a *Apogonia buttikoferi* Ritsema, 1896					1	1	2
a *Apogonia lobata* Ritsema, 1904				3	1	4	8
a *Apogonia sericea* Gestro, 1883	4	18	9	40	34	5	110
a *Apogonia* sp. 1	21	3	31	1	11	2362	2429
a *Apogonia* sp. 2			2				2
a *Apogonia* sp. 3				3			3
a *Apogonia* sp. 4	1	25	9	11	19	14	79
a *Apogonia* sp. 5		7		4	4		15
a *Apogonia* sp. 6		1	1	1			3
a *Apogonia* sp. 7			2		3		5
Hoplini							
b *Hoplia* sp. 1						1	1
a *Hoplia* sp. 2		1					1
Macrodactylini							
b *Dichelomorpha* sp.		1					1
Melolonthini							
b *Asactopholis gracilipes* (Sharp, 1876)		3		2			5
b *Asactopholis laticeps* Moser, 1908		1					1
b *Asactopholis pectoralis* Moser, 1908		3					3
b *Holotrichia waterstradti* Moser, 1912			4	3	4		11
b *Leucopholis sharpi* Brenske, 1896			2	1		1	4
b *Octoplasia princeps* (Sharp, 1876)	1	7	10				18
b *Psilopholis grandis* (Castelnau, 1840)			1				1
b *Schoenherria borneensi*s Brenske, 1894		3	6	5		1	15
Sericini							
a *Maladera* sp. 1		1					1
a *Microserica* sp. 1		1		1	2		4
a *Microserica* sp. 2	1						1
a *Microserica* sp. 3						1	1
a *Microserica* sp. 4		1	9				10
a *Microserica* sp. 5	1	1	7		2		11
a *Microserica* sp. 6				5			5
a *Microserica* sp. 7		2					2
Rutelinae							
Adoretini*							
a *Adoretus compressus* Web., 1801			2		3	2	7
a *Adoretus* sp.	3	2	12	15	7		39
Anomalini*							
d *Anomala diversicolor* Ohaus, 1916	3	16	2	4			25
d *Anomala pallida* Fabricius, 1775			3		1	18	22
d *Anomala psittacina* Ohaus, 1916		3	3	2		11	19
d *Anomala whiteheadi* Arrow, 1910		3		3			'6
d *Anomala* sp. 1		2	3	3	2	1	11
d *Anomala* sp. 2		1					1
d *Anomala* sp. 3						1	1
d *Anomala* sp. 4		17	15	11	6	1	50
d *Anomala* sp. 5	1	1					2
d Callistethus near maculatus?	1						1

Table 2. Cont'd.

Species	Forest Type						
	Primary forest	Isorated primary forest	Rubber garden	Old fallow	Young fallow	New fallow	Total
Rutelini							
d *Parastasia confluens* Westwood, 1842*		13	2	3	3	8	29
d *Parastasia discolor scutellaris* Erichson, 1845*	1	4		3		1	9
Dynastinae							
Dynastini							
c *Allomyrina* sp.		2					2
c *Chalcosoma atlas* (Linnaeus, 1758)	1				1		2
e *Xylotrupes beckeri wiltrudae* Silvestre, 1997	1	1		3	1		6
Oryctini							
e *Blabephorus pinguis* Fairmaire, 1898	2	5	1	1		1	10
e Clyster trachypygus Prell, 1911	1		1	2	3		7
e *Trichogomphus lunicollis alcides* Snellen van Vollenhoven, 1864		3					3
Cetoniinae							
Cetonini							
d *Protaetia ciliata* (Olivier, 1785)				1			1
Total (species richness)	15	32	23	24	19	18	
Total (abundance)	43	154	137	131	108	2434	3007

*According to a preliminary molecular analysis, the tribes Adoretini and Anomalini will need to be elevated to the subfamily level (Smith et al. 2006), and the genus *Parastasia* forms a clade in the subfamily Dynastinae (Smith et al. 2006; K. Wada unpublished data).

group (Fig. 4). Hence Habitat Groups 1 and 3 were more similar to one another in species composition than plots in Habitat Group 2.

DISCUSSION

Our results indicated that scarab beetle species richness was highest in the isolated primary forest (Table 2). Approximately 73% of the species collected in the preserved primary forest (LHNP) were also caught in the isolated primary forest (Table 2). These findings suggest that the presence of isolated primary forests maintains relatively high scarabaeid diversity in the swidden landscape. In the five plots of isolated primary forest, we found 41–61 tree species, whereas 38 and 50 tree species were recorded in H1 and H2 in LHNP, respectively. The high tree-species richness in the isolated primary forests may sustain such high species richness of phytophagous scarab beetles. Alternatively, the scarab communities in isolated primary forests may consist of both forest specialists and disturbance-tolerant species, as previously observed for some taxonomic groups (Gascon et al., 1999; Nakagawa et al., 2006). Moreover, scarab communities in small patches of isolated primary forests may be enriched by movement of the beetles from close-by surrounding landscapes with different vegetation. Thus, the remnant isolated primary forests presumably contribute not only to the livelihood of the local people inhabiting such landscapes in the tropics (*sensu* Ichikawa, 2007) but also to the conservation of biodiversity outside of the preserved areas.

Species diversity did not remarkably differ among the forest types of Habitat Group 3 (Figs. 3, 4). This result may indicate that old and young fallows as well as rubber gardens function similarly in recovering and maintaining biodiversity compared with isolated primary forests. Moreover, the differences in diversity between Habitat Groups 1 and 2 and between Habitat Groups 2 and 3 suggest that if fields remain fallow for more than 5 years after the slash-and-burn phase of swidden cultivation, the biodiversity of some insect taxa, or of at least phytophagous scarabaeids, will be restored to levels similar to the diversity in isolated primary forests. This information should prove useful for land-use planning that is conscious of biodiversity conservation in the tropics. However, our study did not take into consideration temporal variations. Since phytophagous beetle populations tend to temporally fluctuate in Bornean rainforest (Kishimoto-Yamada & Itioka, 2008a, b; Kishimoto-Yamada et al., 2009), further studies are required to corroborate our findings.

On the other hand, scarabaeid diversity did not significantly differ between Habitat Groups 1 and 3 (Figs. 3, 4). Furthermore, species richness and abundance were lowest in the primary forest (Table 2). These results should be interpreted with caution. Kato et al. (1995) and Kishimoto-Yamada & Itioka (2008a) demonstrated that in LHNP, phytophagous beetles, including Scarabaeidae, were more abundant in the canopy (>15 m above the ground) than at the forest floor. Similarly, we observed night-flying scarabaeids feeding on tree leaves much more frequently in the canopy than on the forest floor. These results suggest that most of the target scarabaeid species likely perform flying activities primarily in the canopy, especially in the primary forests. Because our light trapping was conducted on the forest floor, species diversity may have been underestimated in the preserved primary forest in this study. Future studies incorporating spatial and temporal variations in beetle diversity are warranted.

The lowest values of community evenness occurred in the new fallows, likely because these systems were dominated by one species of the genus *Apogonia* (Table 1). The host plants of Melolonthinae, including *Apogonia*, are diverse, and they depend on grasses as well as trees (Hill, 1983). Furthermore, the new fallows at the study site were characterised by thick Cyperaceae grasses (Nakagawa et al., 2006). These facts suggest that the dominant *Apogonia* species may feed on Cyperaceae grasses. If this supposition is true, the *Apogonia* species likely occurred in large numbers due to the rich supply of Cyparaceae grasses. The ecological traits of species such as host plants should be investigated in more detail in future studies. In addition to the *Apogonia* species, a stinkbug species was also very abundant in only the new fallows (Kishimoto-Yamada et al., unpublished). Similar outbreaks of a few species have been reported for ants inhabiting lands where swidden cultivation had only recently ceased (Ewium et al., 1997; Tanaka et al., 2007). These findings indicate that a reduced fallow period could potentially drastically reduce the evenness of the arthropod community. Previous studies have postulated that reduced community evenness may damage ecosystem processes (Wittebolle, 2009). Alternatively, it may contribute to outbreaks of potentially harmful pests in agricultural systems.

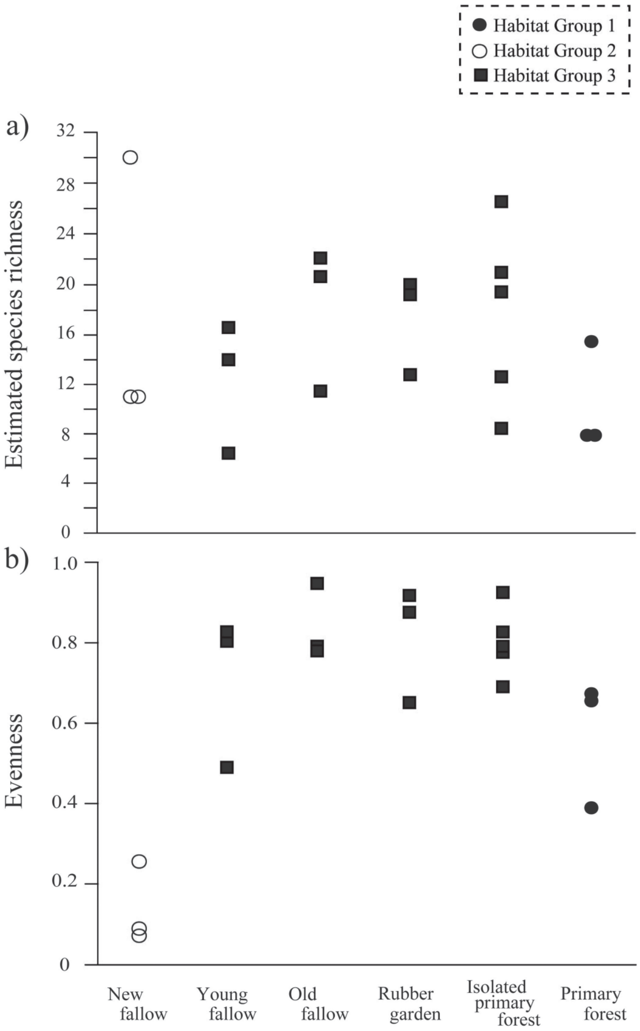

Fig. 3. Values of Chao1 estimated species richness (a) and values of Simpson's evenness index (b) of the phytophagous scarab beetles across forest types.

The results of our study emphasize that the roles of swidden land, which is often undervalued (see reviews of Mertz, 2009 and Fox et al., 2009), should be reevaluated in terms of biodiversity conservation value. In this study, we concluded that rubber gardens and fallows, which are generated in the process of swidden cultivation at relatively small spatial scales within the landscape, contribute at some level to the conservation of phytophagous scarabaeid community diversity. The contribution of such forest types to biodiversity conservation has also been suggested for the small mammal community at the same study site (Nakgawa et al., 2006). However, to what degree such types of forests affect biodiversity conservation appears to vary among taxa. The effect is likely to be minimal for communities of army ants (Matsumoto et al., 2009), ants mutualistically associated with other organisms (Tanaka et al., 2007), and butterflies (Itioka et al., unpublished). The factors affecting such variation among taxa remain to be elucidated. Future studies of these factors will provide valuable information for biodiversity conservation in the Southeast Asian tropics, where swidden cultivation is an important anthropogenic activity.

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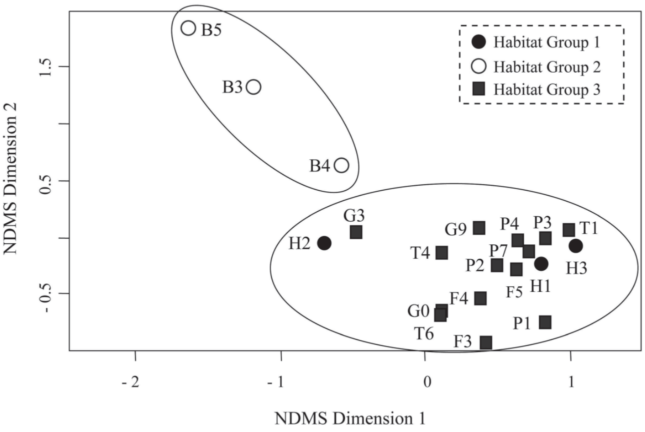

Fig. 4. Ordination diagram of NMDS scores (along the first two axes) for the scarab beetle community in the study plots.

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