Community Structure of Aphyllophoraceous Fungi and Impacts of Human Forest Use in Sarawak, Malaysia

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Introduction

Fungi play important roles as decomposers and symbionts of plants in forest ecosystems and should contain enormously diverse species. Hawksworth and Mueller (2005) estimated the number of fungal species to be between 600 000 and 1 500 000 and suggested that there are hot spots of fungal diversity in the tropical region. Pegler (1997) also pointed out that Southeast Asia has possibly the greatest species diversity of fungi. However, information on the fungal community structure in the tropical forest is almost limited to that of Aphyllophorales in the neotropical region (Ferrer and Gilbert 2003; Schmit 2005; but see Hattori and See 2003). In addition, natural forests, which would support high fungal species diversity, are disappearing at an annual rate of 1.4% in Southeast Asia (Sodih et al. 2004). Thus, reliable and rapid evaluation of fungal community structures under undisturbed conditions in Southeast Asia is greatly needed.

It is well known that fungal flora and their species diversity are affected by forest environmental factors (e.g., Yamashita and Hijii 2006). Human uses of the forest affect the composition and diversity of macrofungi, such as Agaricales and Aphyllophorales in temperate and boreal zones (e.g., Penttilä et al. 2004; Sippola et al. 2004). Forest use in tropical regions is also expected to affect fungal community structure, although studies on the effect of forest use on the fungal community structure in this region are rare.

Although long-term study is needed to adequately characterize the fungal flora (Mueller et al. 2004), rapid assessments are still helpful for monitoring and managing rapidly changing tropical forests. Because fruiting bodies of bracket fungi and shelf fungi (Aphyllophorales, Basidiomycetes), which mainly utilize fallen logs, twigs, and other woody materials as their substrates, are long-lasting, year-to-year variation in species composition is smaller than that of ephemeral fungi, such as agaric mushrooms (Berglund et al. 2005). Aphyllophorales has also been taxonomically well described; thus, it provides suitable candidates of environmental indicators that could be used to examine the effects of forest use in tropical regions.

In this study, we conducted field survey and estimated the number of fungal species to reveal the community structure of aphyllophoraceous fungi in the primary forest. We compared fungal species density and species composition among five forest types (rubber plantation, land left fallow after rice cultivation for less than 10 years, land left fallow after rice cultivation for more than 30 years, isolated and fragmented primary forest, and primary forest) to reveal the effects of human forest use on the aphyllophoraceous fungal community

Methods

The study area is located in and around Lambir Hills National Park, Sarawak, Malaysia (4º20'N, 113º50'E). Aphyllophorales is a taxonomically polyphyletic group, but almost all species are pathogenic or saprotrophic fungi. We focused on polypores, hydnoid fungi, and stereoid fungi, but we excluded clavarioid and corticioid fungi because it is very difficult to identify species in these two groups. After identifying the fungi to the species or morphospecies level, we collected fruiting bodies and preserved them as dried specimens at the Sarawak Forestry Corporation (Forest Research Center) in Kuching, Sarawak, Malaysia.

To reveal the aphyllophoraceous fungal community structure in the primary forest, we established twelve 100×10 m transects which is divided into forty 5×5 m quadrats in the park. We collected all fruiting bodies of Aphyllophorales in these transects in June and December 2006. At the same time, we recorded the diameter and decay stage of the coarse woody debris (CWD) on which the fruiting bodies appeared. Because the number of fruiting bodies does not always correspond to the number of fungal individuals, we used the number of CWD on which almost all species occurred as that of individuals. For fruiting bodies of *Amauroderma subrugosum* and other fungi which appeared directly from the ground, we treated the number of 5×5 m quadrats as the number of individuals. We estimated the number of aphyllophoraceous fungal species using three estimators: Chao 1, Chao 2, and Jackknife 1.

To reveal the effects of forest use on the fungal community, we established 10 plots in and around the park. Two plots were established for every forest type: rubber plantation, land left fallow after rice cultivation for less than 10 years, land left fallow after rice cultivation for more than 30 years, isolated and fragmented primary forest, and primary forest. In a primary stand in the park, two study plots were established. The other plots were established around the park. In each plot, we established one long band transect (10 m wide and 100 m long) and recorded tree composition, soil water potential, the degree of canopy openness, and the mass of forest-floor leaf and branch litter (Yamashita et al. in press). Perpendicular to each long transect, we established four shorter band transects (5 m wide and 40 m long) at intervals of 25 or 50 m, in which we recorded the number of CWD pieces. We collected all fruiting bodies that appeared in the short band transects from 17 June to 6 September 2005. We used the number of branch transects in which these species occurred because the number of fruiting bodies does not always correspond to the number of fungal individuals.

We used canonical correspondence analysis (CCA) to reveal the relationships between fungal community composition and the environmental variables (Jongman et al. 1995). We performed preliminary principal-components analysis (PCA) for plant species composition so that we could use the PC axes as factors related to plant species composition. The PCA revealed that plant species composition in the rubber plantation and the young fallow forest differed conspicuously from each other and from that in the other forest types. Differences in the composition of CWD among plots were also evaluated by using the PCA scores, and the PCA results for CWD composition showed no clear grouping. We used the degree of canopy openness, soil water potential, the scores for PC-1 and PC-2 for the composition of CWD, the total number of pieces of CWD, the dry weight of litter, the scores of PC-1 and PC-2 for plant species composition, and the total basal area of the plot as environmental variables in the CCA.

Results

Fungal community structure in the primary forest

A total of 721 individuals from 101 species was collected from the 1.2 ha of transects. The estimated numbers of species were 155 (Chao 1), 161 (Chao 2), and 147 (Jackknife 1). Almost half of these species were singletons. Dominant species were *A. subrugosum*, *Ganoderma austrael*, *Microporus xanthopus*, and *Microporus affinis* (> 40 individuals in total). *Ganoderma australe* tended to appear on large fallen trunks, whereas *M. xanthopus* and *M. affinis* appeared on fallen branches.

Effects of forest use on the fungal community

The environmental variables are shown in Table 1. Canopy openness ranged from 6.1 to 10.5%, soil water potential from -586 to -23 kpa, number of pieces of CWD from 13 to 533 per ha, leaf and branch litter from 0.54 to 1.16 kg dry wt./m^2, and basal area from 11.5 to 74.6 m^2/ha.

A total of 155 samples from 67 species of polypores, hydnoid fungi, and stereoid fungi was collected during the study period. *Amauroderma subrugosum* and *Trametes* cf. *mimites* were dominant species in the study stands. Twenty-eight aphyllophoraceous species appeared in more than two transects, whereas 39 species were singletons.

The species density (number of species per 200 m^2) differed significantly among forest types ($P < 0.05$) but not among site positions ($P > 0.05$), and the interaction between forest type and site position was not significant ($P > 0.05$; Fig. 1). More than four species per 200 m^2 appeared in the rubber plantation, isolated primary forest, and primary forest. The fungal species density increased significantly with increasing number of pieces of CWD in the short band transect (Pearson's correlation coefficient; $r = 0.842$, $P < 0.05$), but it decreased significantly with increasing PC-2 scores for plant species composition ($r = -0.803$, $P < 0.05$).

In the CCA ordination, the first axis explained 23.1% of the total variance versus 17.4% for the second axis (Fig. 2). Automatic forward selection revealed that only the number of pieces of CWD significantly affected the fungal species composition (Monte Carlo permutation test, $P < 0.05$). The occurrences of *Flabellophora licmophora* (*Flic*), *Coriolopsis retropicta* (*Cret*), *Microporus vernicipes* (*Mver*), and *A. subrugosum* (*Asub*) were positively correlated with the number of pieces of CWD.

Fungal flora in the young fallow forest near the park and the old fallow forest near the village were clearly different from those in the other plots. The other eight plots were clustered at the central part of the diagram. Young fallow forest near the park and old fallow forest near the village were associated with *Podoscypha nitidula* (*Pnit*) and *Podoscypha* sp. 1 (*Psp1*), respectively.

Discussion

Four of the world's 25 biodiversity hot spots for plants and vertebrates are in Southeast Asia (Myers et al. 2000), and the study area is famous for its diverse plant species. Our study revealed that primary forest in this region maintains a high species diversity of Aphyllophorales compared with temperate and boreal zones

(10 to 89 species; Schmit 1999; Penttilä et al. 2004).

Community structures of living organisms other than fungi are affected by anthropogenic forest use in tropical regions (Waltert et al. 2003; Yasuda et al. 2003). Schulze et al. (2004) revealed that almost all the species groups or guilds of plants, birds, and insects could not accurately predict the biodiversity of other groups. A previous study at our study site revealed that the diversity of small mammals did not differ clearly among forest types (Nakagawa et al. 2006). Conversely, except at the rubber plantation (which had a high amount of CWD), our study showed that human forest use negatively affected aphyllophoraceous fungal diversity. This suggests that fungal diversity could indicate some aspects of a forest's environmental condition, such as the quantity of CWD. In boreal and temperate regions, the community structure of both ectomycorrhizal fungi (Visser 1995) and wood-inhabiting fungi (Penttilä et al. 2004) were strongly affected by forest management. Iwabuchi et al. (1994) showed that the species diversity of macrofungi increased as successional changes occurred in plant species composition. Hence, the response of the species diversity of macrofungi to forest disturbance appears to not differ greatly among regions.

Recently, studies of the community structure of decomposers have stressed the importance of management of CWD to maintain species richness of saproxylic fungi and other living organisms (Jonsson and Kruys 2001; Lindhe et al. 2004; Jonsson et al. 2005) because the abundance of CWD is positively correlated with the species richness of both rare and common wood-inhabiting fungi (Penttilä et al. 2004). Our results also showed that the abundance of CWD affected the species richness and composition of aphyllophoraceous fungi in the stands. This suggests that overuse of CWD in tropical regions, such as harvesting it for fuel, would negatively affect the fungal community that develops on CWD, with consequences such as a loss of species diversity and of functional groups.

Species diversity of the Aphyllophorales reflected forest conditions, especially the quantity of CWD, but species diversity might not be the best indicator of forest conditions in very different habitats. In our study, tree composition differed between rubber plantations and the other types of forest, but the number of fungal species was similar to those in isolated primary forests and primary forests. Some species, such as *A. subrugosum*, which appeared mainly in primary and isolated primary forests and was one of the dominant species in the primary forest, could be good indicators of forest condition. Both species diversity and the presence of indicator species have shortcomings, and further study is needed to elucidate good indicators of forest condition.

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Table 1 Environmental variables for each study plot.

Plot	Position	Canopy Openness (%)	Soil Water Potential (Kpa)	CWD (pieces/ha)	Litter (g dry wt./ m^2)	Basal Area (m^2/ha)
R	Near park	10.5	-582	415	0.98	52.4
	Near village	7.0	-73	295	0.54	54.8
YF	Near park	9.1	-53	165	0.90	11.5
	Near village	9.7	-156	13	0.73	24.7
OF	Near park	7.8	-240	283	0.95	54.2
	Near village	7.7	-545	150	1.16	74.6
IP	Near park	6.1	-586	438	1.08	70.9
	Near village	7.0	-323	305	1.11	74.7
P1	-	6.8	-84	403	1.14	73.4
P2	-	6.9	-23	533	1.16	64.2

Sample statistics except for basal area are means, where number of samples of canopy openness and water potential was 10, that of CWD was 4, and that of litter was 5. After Yamashita et al. (in press).

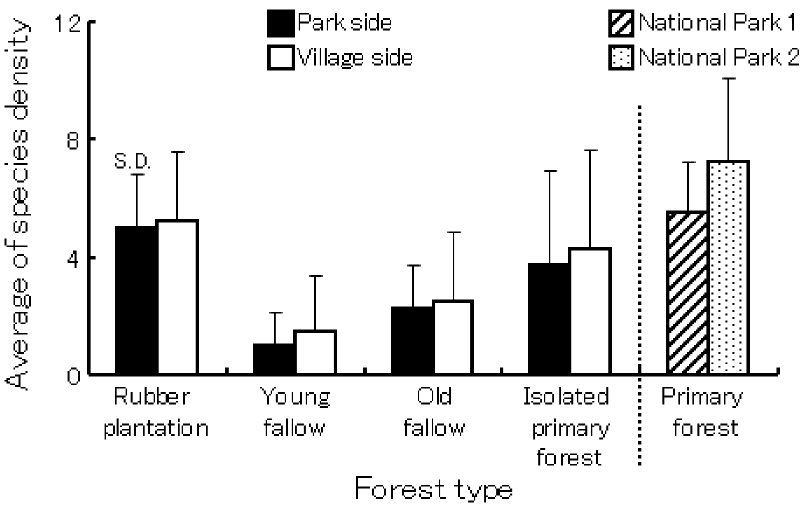

Fig. 1 The average of aphyllophoraceous species density per $200m^2$ found in each plot (n = 4 short band transects). Species density differed significantly differed among forest types (P = 0.007) but not among site positions (park vs. village), and there was no significant site-forest type interaction (two-way ANOVA). The species density in P2 was significantly higher than those in young fallows (one-way ANOVA, Tukey-Kramer's HSD test, $P < 0.05$). After Yamashita et al. (in press).

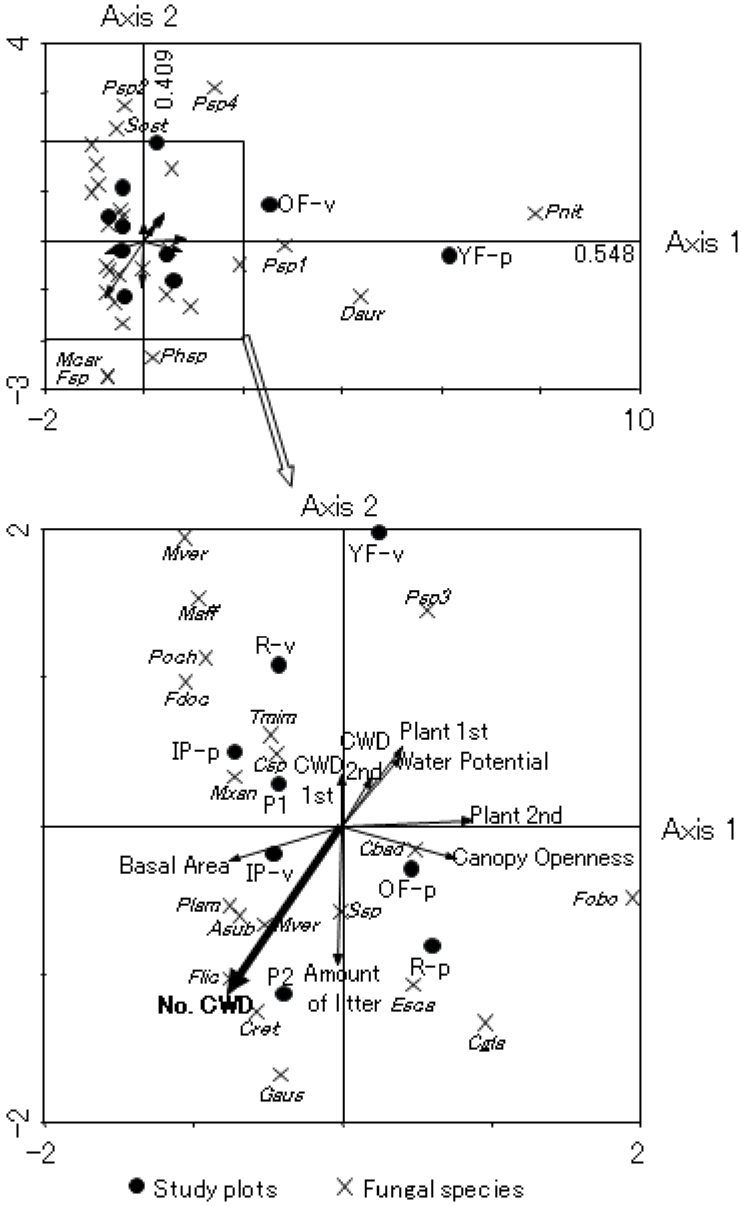

Fig. 2 The results of a canonical correspondence analysis ordination for the site scores of the study plots and the correspondence positions of the aphyllophoraceous species. The upper graph shows all plots and species; the lower graph shows plots and species that lie within 2units on either side of the origin. Environmental variables are shown by arrows. Numbers on the axes are eigenvalues. Variables with a significant effect are shown in bold (Monte Carlo Permutation test, $p < 0.05$). -v, near village; -p near park. After Yamashita et al. (in press).