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# The Impact of the 1998 Forest Fire on Ectomycorrhizae of Dipterocarp Trees and their Recovery in Tropical Rain Forests of East Kalimantan, Indonesia

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## Abstract

The impact of forest fire in 1997 and 1998 on the mycorrhzae was studied at the dipterocarp forest in East Kalimantan, Indonesia. In unaffected forest more than half of total ectomycorrhizae distributed in the organic layer but in the fire-affected forest one and a half years after the fire, total amount of mycorrhizae was smaller and they were found in deeper soil. The number of morphotypes of mycorrhizae was also smaller in fire-affected forest. An artificial plantation established after clear cut and prescribed burn had the largest amount of ectomycorrhizae, but the diversity was smaller than the unaffected forest. After four years, mycorrhizae had not yet recovered in fire-affected forest although the organic layer had recovered. Pioneer species of mycorrhizal fungi (early-stage fungi) developed sporocarps around the surviving hosts in severely affected forest and this suggests the start of secondary succession of mycorrhizae. In moderately affected forest, the species composition of mycorrhizal fungi which fruited during the study was similar to those of unaffected forest. This fact suggests that such sites may be the refugia of symbionts and be important in reforestation.

**Discipline:** Forestry and forest products
**Additional key words:** diversity, reforestation, refugia, safe site, succession

## Introduction

Dipterocarp trees are dominant species in tropical rain forests of Southeast Asia and are also the most important commercial trees in this area. In the tropics, arbuscular mycorrhiza is the dominant type of mycorrhiza[12] and dipterocarp trees form arbuscular mycorrhizae[15], but they are well known to be ectomycorrhizal and cannot survive without ectomycorrhizae[14].

The general functions of ectomycorrhizae are the promotion of the nutrient and water uptake from the soil[8], and the enhancement of the protection against soil borne disease[7] and deleterious compounds or ions. Ectomycorrhizal fungi also act as shortcut pathways of nutrient recycling from decomposing litter[10]. Mycorrhizal fungi usually have limited capability to decompose complex organic compounds[5], but the hyphae in the decomposing litter may absorb the inorganic nutrients released by litter decomposers. Although this function is not proved in dipterocarp species, Vogt et al. mentioned the nutrient recycling in the Amazon[17], and Allen suggested the participation of mycorrhizal fungi[4]. In the tropics where soil is poor in nutrients, the ability to intercept diffusing nutri-

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ents must be very advantageous.

A huge area of Kutai prefecture, province of East Kalimantan, suffered forest fires during the severe drought in 1997 and 1998. Forest fire often kills host trees and this is fatal to ectomycorrhizal fungi because they are virtually obligate symbionts. However, even if the host trees survived, mycorrhizae can be seriously damaged by the burning of the litter layer and consequent heating of top soil because mycorrhizae distribute mainly in the top soil[3]. In dipterocarp trees, the loss of the functions of ectomycorrhizae may be a very serious problem to the recovery from the forest fire, because they largely depend on mycorrhizae for the function of the roots.

The objective of this study is to show the effect of forest fire on the status of ectomycorrhizae and to estimate the damage and recovery of underground parts of dipterocarp forest. In the former part of this study, conducted one and a half years after the forest fire, mycorrhizae were collected from the soil of fire-affected forest, neighboring unaffected forest and artificial plantation, and they were analyzed for the biomass and diversity to show the damage. In the latter part of the study, conducted three years after the former one, occurrence of mycorrhizal mushrooms and distribution of mycorrhizae were examined in heavily and lightly disturbed forests and undisturbed forest to show the recovery of mycorrhizae and their diversity.

## Materials and methods

### 1. Study site

The study was conducted at Bukit Bangkirai nature reserve of PT INHUTANI-1, a state-owned forestry company, and Sebulu Experimental Forest of Kutai Timber Indonesia, both in East Kalimantan. Bukit Bangkirai (1°01’S, 116°52’E) is located in Samboja district, Kutai Kartanegara regency, 25 km north of Balikpapan and the altitude is ca. 110 m. The area had suffered forest fire and some limited part of the nature reserve was severely burnt; almost all canopy trees were lost (Fig. 1). Another area suffered only moderate ground fire which burnt shrubs on the forest floor and many but not all canopy trees died standing (Fig. 2) from the damage to their cambium caused by the heat of the ground fire. An unaffected area (Fig. 3) had high diversity of vegetation which contained more than 500 species of plants. The major woody families recorded in Bukit Bangkirai are Annonaceae, Dipterocarpaceae, Euphorbiaceae, Lauraceae, Myrtaceae, and Rubiaceae. The dominant tree species were *Shorea laevis, Dipterocarpus confertus, Cotylelobium motleyanum, Cleistanthus myrianthus, Ancistrocladus tectorius, Derris elegans, Stachyphrynium jagori-*

**Fig. 1. The severely fire-affected forest in Bukit Bangkirai three years after the fire**
Most of the canopy trees are killed and the ground is covered by ferns and herbaceous plants.

**Fig. 2. The moderately fire-affected forest in Bukit Bangkirai two years after the fire**
The canopy is open but some of the mycorrhizal host trees survived the fire.

**Fig. 3. The unaffected natural forest in Bukit Bangkirai**
There are many mycorrhizal emergent and canopy layer trees and a diverse understory layer.

*anum*, and *Maesa ramentacea*[1]. There were some *Lithocarps* trees which are considered to be mycorrhizal. Sebulu Experimental Forest is located about 80 km north of Bukit Bangkirai. The stand where we collected samples was an experimental plantation of *Shorea leprosula* established in 1993 at 10,000 trees/ha density. The forest floor of the plantation is shown in Fig. 4. We visited Bukit Bangkirai and Sebulu in 1999 for the study of mycorrhizal biomass and diversity. In 2002, we visited Bukit Bangkirai to study the mycorrhizal distribution and the species composition and succession of mycorrhizal fungi.

**2. Biomass and diversity of mycorrhizae**

**(1) Sampling**

In August of 1999, soil samples were collected on a partly fire-affected small hill. We collected samples around the foot of a *Shorea laevis* tree in an unaffected area and around one surviving *S. laevis* tree in a moderately fire-affected area just across the border of the areas. There were some severely burnt patches in the moderately affected area, and we collected samples from severely and moderately fire-affected sites separately. We also collected samples from a young plantation in Sebulu Experimental Forest in September. Numbers of the samples were 8 in severely and moderately affected sites, 7 in the unaffected site and 6 in the plantation.

The ground was covered by leaf litter in the unaffected site and plantation. In the severely affected site, there was no litter except carbonized or freshly-fallen dry litter. In the moderately affected site, the amount of litter was small and the ground was not covered entirely. There was a carbonized top layer in the severely affected site, and the thickness was 1.7 cm in average. In the unaffected site, there was 3 to 4 cm of A-horizon which contains humus, but there was no recognizable A-horizon in the plantation although there were 0.5 to 1 cm of $A_O$-horizon both in the unaffected site and the plantation.

We collected soil samples under the crown of *Shorea laevis* trees, 3 to 6 m from the foot of them in Bukit Bangkirai, and randomly in the Sebulu plantation. When there was freshly-fallen dry litter on the ground, it was removed before sampling the soil. The size of soil samples was 10 cm square and 5 cm in depth. Samples were taken undisturbed and packed in polyethylene bags.

**Fig. 4. Forest floor in a 6-year-old plantation of *Shorea leprosula* in Sebulu Experimental Forest**
The density is 10,000 trees/ha.

**(2) Grouping of mycorrhizae**

Soil samples were brought to the laboratory in PUSREHUT, and sliced into three subsamples: top 1 cm, middle 2 cm and bottom 2 cm. All the plant roots were picked up and fine dipterocarp roots bearing mycorrhizae were separated from other roots and mycorrhizae were excised from the fine tap roots under dissecting microscope. Mycorrhizae were sorted into several types mainly by their surface structures, which are more stable than other characteristics and depend on fungi rather than host[2]. The sorted mycorrhizae and the fine tap roots were desiccated in a drying oven at 60°C for 1 day, and weighed.

**3. Distribution of ectomycorrhizae and sporocarps**

The study was conducted in July, 2002 in Bukit Bangkirai. Three permanent plots which each covered an area of ca. 1 ha had already been established by the research project of Indonesian Institute of Sciences and the Ministry of the Environment of Japan in 2001 and we collected samples from them. The name of the plots were HD for severely fire-affected (heavily disturbed), LD for moderately fire-affected (lightly disturbed) and K for unaffected (K is the initial of the Indonesian word for “control”) plot, respectively. Soil samples were collected as blocks of soil 10 cm square and 5 cm in depth. Numbers of the samples were 16 for K and HD plots, and 12 for the LD plot. The sampling points are shown in Fig. 5. Samples were separated into the organic layer and mineral soil and washed under running water. Mycorrhizal roots were sorted using dissecting microscope and the amount was classified into no mycorrhiza and four arbitrary groups of several mycorrhizal root tips (present but few), small amount (around 10 mg in fresh weight), moderate amount (about 10 to 100 mg), and large amount (apparently more than 100 mg).

All terrestrial mushrooms and toadstools except saprophytic species were collected from each plot and recorded.

## Results and discussion

### 1. Biomass and diversity of mycorrhizae

### (1) Biomass of mycorrhizae

Table 1 shows the biomass of mycorrhizae in the soil samples collected from variously fire-affected sites in Bukit Bangkirai and the plantation in Sebulu Experimental Forest. There was entirely no mycorrhiza in the severely affected site. The biomass of mycorrhizae was the smallest in the moderately affected site among three mycorrhiza-containing sites and the distribution did not depend on the depth. In the unaffected site and the plantation, most of the mycorrhizae were distributed in the top 1 cm layer, $A_0$-horizon. However, the tendency was not significant in the unaffected site (Friedman's test) probably because of the insufficient number of samples which

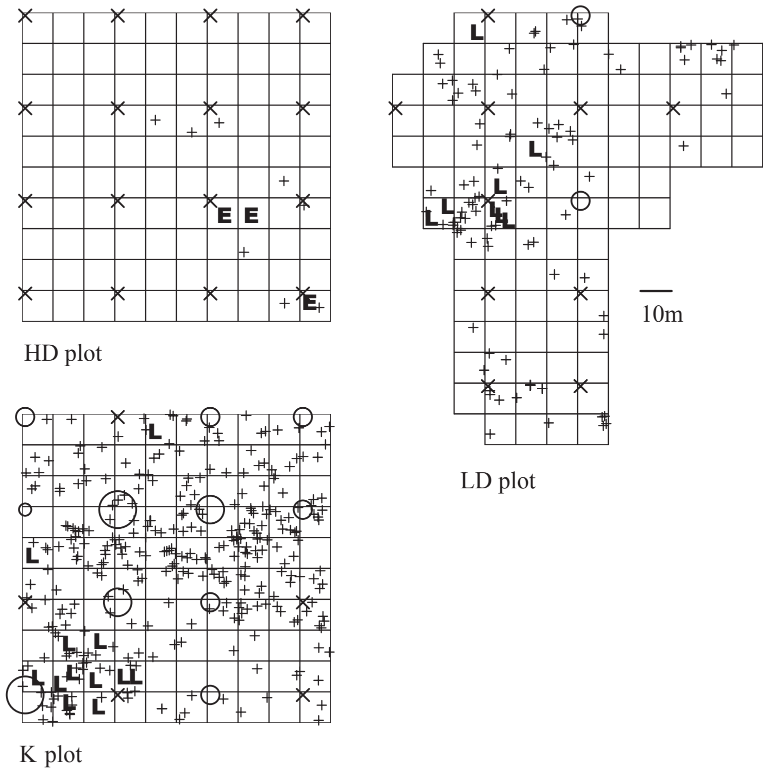


**Fig. 5. The amount of mycorrhizae and the distribution of mycorrhizal trees and mycorrhizal mushrooms in severely and moderately affected (HD, LD) and unaffected (K) plots in 2002 study**

Circles and "×" symbols represent the amounts of mycorrhizae at each point ("×" means no mycorrhiza, small to large circles mean small to large amounts of mycorrhizae, respectively). Mycorrhizal trees (Dipterocarpaceae and Fagaceae) are shown by "+". Letters show the position of the sporocarps of mycorrhizal fungi (E: Early-stage fungi; L: Late-stage fungi).

**Table 1. Total biomass of mycorrhizae contained in samples collected one and a half years after the fire in severely and moderately fire-affected sites, unaffected site and plantation**

| Depth | Sampling site | | | |
|---|---|---|---|---|
| | Severely affected | Moderately affected | Unaffected | Plantation* |
| 0–1 cm | 0 (0/8) | 4.2 ± 5.2 (4/8) | 15.8 ± 7.2 (5/7) | 22.6 ± 3.7 (6/6) |
| 1–3 cm | 0 (0/8) | 5.3 ± 2.4 (6/8) | 5.6 ± 3.4 (4/7) | 8.8 ± 2.9 (6/6) |
| 3–5 cm | 0 (0/8) | 5.7 ± 4.2 (6/8) | 2.7 ± 4.1 (3/7) | 2.4 ± 1.3 (5/6) |
| Total | 0 (0/8) | 5.2 ± 9.9 (6/8) | 24.1 ± 8.7 (6/7) | 33.8 ± 5.7 (6/6) |

Values are average dry weight (mg) ± SE. Numbers in parentheses are the number of mycorrhiza containing samples / all samples.
*: The distribution of mycorrhizae was significantly biased ($p < 0.01$, Friedman's test).

contained mycorrhizae and this might be caused by the heterogeneous spatial distribution of mycorrhizae in the natural forest.

**(2) Diversity of mycorrhizae**

Mycorrhizae were sorted into 13 types according to the surface structures. The dry weight of each type of mycorrhiza is shown in Table 2. Eight types were observed in the unaffected site while the moderately affected site had only four and there were two types in common. The unaffected site had two other types common with the plantation. Almost all of the mycorrhizae in the moderately affected site were type 2, but in the unaffected site the most abundant type (type 10) accounted for only one third of the total. Type 2, 8 and 10 are shown in Fig. 6. The plantation had only five types of mycorrhizae although the biomass was the largest. The host trees of the plantation were 6-year-old and planted after clear cut and prescribed burn, so they might be similar to the regenerating forest after forest fire except that host trees were supplied immediately after the fire. The mycorrhizal diversity of the plantation was less than the unaffected site. This suggests that once the mycorrhizal diversity was destroyed the recovery takes a long time even if many host trees are present.

**Table 2. The biomass of each morphotype of mycorrhizae in the moderately fire-affected site, unaffected site and plantation**

| Type | Sampling site | | | Total |
|---|---|---|---|---|
| | Moderately affected | Unaffected | Plantation | |
| 1 | 2.8 | – | – | 2.8 |
| 2 | 117.6 | 4.8 | – | 122.4 |
| 3 | 1.0 | – | – | 1.0 |
| 4 | 1.0 | 20.9 | – | 21.9 |
| 5 | – | 5.4 | 1.1 | 6.5 |
| 6 | – | 28.1 | – | 28.1 |
| 7 | – | 24.3 | – | 24.3 |
| 8 | – | 8.0 | – | 8.0 |
| 9 | – | – | 49.9 | 49.9 |
| 10 | – | 62.6 | 81.0 | 143.6 |
| 11 | – | – | 13.5 | 13.5 |
| 12 | – | – | 57.1 | 57.1 |
| 13 | – | 15.4 | – | 15.4 |
| Total | 122.4 | 169.5 | 202.6 | 494.5 |

Values are dry weight (mg).

The moderately affected site had the fewest types and the least biomass of mycorrhizae, and their distribution seemed not to be correlated with the soil depth. On the other hand, the unaffected natural forest had the most types of mycorrhizae and more than half of them were distributed in the top 1 cm layer. This layer almost corresponds to the organic layer which was lacking in fire-affected sites, so it appears that the topmost 1 cm of soil is essential for the mycorrhizal development and diversity in dipterocarp forests.

## 2. Distribution of ectomycorrhizae and sporocarps

The thickness of $A_0$ and A horizons in K, LD and HD plots is shown in Table 3. The appearance of mycorrhizae in each plot is shown in Fig. 5. The small crosses

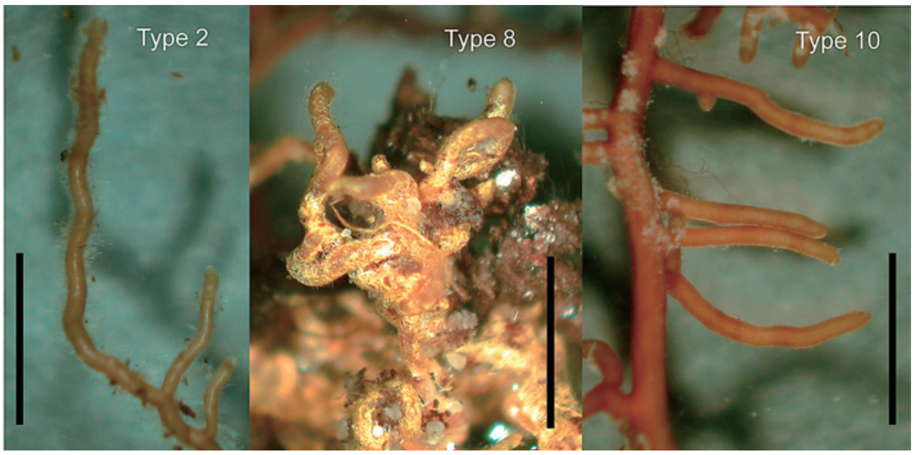


**Fig. 6. Mycorrhizae found in 1999 study**

Type 2 dominated in the moderately affected site but appeared in small amounts in the unaffected site. Type 8 appeared only in the unaffected site. Type 10 was found in large amounts both in the unaffected site and plantation. Bars are 5 mm.

in the figures are putative ectomycorrhizal trees (belonging to Dipterocarpaceae and Fagaceae). Entirely no mycorrhiza was found in HD, and only two out of 12 samples contained mycorrhizae in LD. On the other hand 11 out of 16 samples contained mycorrhizae in K. The density of mycorrhizal trees seemed not to be related to the distribution of mycorrhizea in both K and LD plots. This suggests that the distribution of ectomycorrhizae is heterogeneous and not restricted under the host trees.

Sporocarps of mycorrhizal fungi were collected in all plots including HD where no mycorrhiza was found in the soil samples. The collected species of ectomycorrhizal fungi are listed in Table 4. The only ectomycorrhizal fungi collected in HD was *Laccaria vinaceoavellanea* Hongo and the *Laccaria* species are known to be early-stage fungi. All the other fungi collected in LD and K plots belonged to late-stage genera[11].

**Table 3. Thickness of $A_0$ and A horizons of each plot in the 2002 study**

| Horizon | Plot | | |
|---|---|---|---|
| | HD | LD | K |
| $A_0$ | 1.9 ± 0.2 | 3.0 ± 0.3 | 1.8 ± 0.2 |
| A | 6.5 ± 0.5 | 5.9 ± 0.8 | 5.9 ± 0.5 |

HD and LD are severely and moderately fire-affected (hardly and lightly disturbed) sites respectively, and K is an unaffected natural forest. Values are average depth ± SE (cm).

The species of ectomycorrhizal fungi occurring on the forest floor are well known to change according to the succession of the forest[6] from early-stage fungi to late-stage fungi[9] even when the forests are artificial plantations[11]. Succession of ectomycorrhizal fungi after forest fire is reported in *Pinus banksiana* forest which is adapted to forest fire[16]. *Pinus banksiana* disperses seeds when their cones are heated by the fire, and the seedlings, which germinate on the forest floor where the organic deposition is burnt, develop mycorrhizal symbiosis with early-stage fungi and the symbionts change to the late-stage with the growth of the trees. In this case, numerous seedlings are supplied immediately after the forest fire and develop mycorrhizae. However, such supply of seedlings subsequent to the fire does not take place in dipterocarp forest, so some surviving trees are important as refugia of mycorrhizal fungi for the re-establishment of mycorrhizal seedlings. Once the symbionts disappear completely, reforestation could be very difficult because mycorrhizal fungi are essential for the safe site of mycorrhizal trees[13] especially in harsh environments.

The only early-stage fungus collected in this study was *L. vinaceoavellanea* which occurred only in HD and all the others collected in LD and K belong to the genera known as late-stage fungi. This suggests that the original mycorrhizal biota in HD, the total of the diverse species of mycorrhizal fungi and their hosts which may have been similar to those of LD and K, was completely de-

**Table 4. Mycorrhizal mushrooms collected in and around the plots**

| Family | Species | Stage | Plot | | |
|---|---|---|---|---|---|
| | | | HD | LD | K |
| Tricholomataceae | *Laccaria vinaceoavellanea* | early | 6 | (20+) | |
| Amanitaceae | *Amanita melleiceps* | late | | | (2) |
| | *Amanita* sp.1 | late | | (2) | |
| | *Amanita* sp.2 | late | | 2 | |
| Boletaceae | *Boletus* sp. | late | | 2 | |
| Hydnaceae | *Hydnum repandum* | late | | 10 | 5 (4) |
| Russulaceae | *Russula castanopsis* | late | | | 20+ |
| | *Russula rosacea* | late | | 7 | 3 |
| | *Russula* sp.1 | late | | | 1 |
| | *Russula* sp.2 | late | | | 1 |
| | *Russula* sp.3 | late | | 1 | |
| | Lactarius sp. | late | | 1 | |

"Stage" shows the putative successional stage of each fungus assumed from the genus. Values in parentheses show the number of mushrooms collected around the plot. The "+" means the existence of the ruins of mushrooms which are difficult to count.

stroyed by the ground fire which burnt the organic layer and secondary succession had started on the regenerating roots of the few surviving dipterocarp trees. On the other hand, the sporocarps of the late-stage fungi in LD show that the mycorrhizal biota in LD has been kept although there were some carbonized soil and early-stage species around the plot which show the damage to the organic layer and mycorrhiza. Not to mention the undisturbed site like K, the mycorrhiza-keeping sites like LD may act as an "ark" for the mycorrhizal diversity which includes species adapted to various host trees, even if the vegetation is not perfectly preserved.

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## References

1. Abe, Y. et al. (2003) Studies on the impacts of forest fires on natural resources and on the evaluation of restoration of ecosystems. Global Environment Research Fund, Ministry of the Environment, Tokyo, Japan, 55-103 [In Japanese]. http://www.env.go.jp/earth/suishinhi/wise/j/J02E0200.htm.
2. Agerer, R. (1987) Colour atlas of ectomycorrhizae. Einhorn-Verlag Eduard Dietenberger GmbH Schwäbisch Gmünd, München, Germany.
3. Akema, T. & Futai, K. (2004) Ectomycorrhizal development in a *Pinus thunbergii* stand in relation to the location on a slope and their effects on tree mortality from pine wilt disease. *J. For. Res.*, **10**, 93–99.
4. Allen, M. F. (1991) The ecology of mycorrhizae. Cambridge University Press, New York, 108–120.
5. Colpaert, J. V. & Van Tichelen, K. K. (1996) Decomposition, nitrogen and phosphorus mineralization from beech leaf litter colonized by ectomycorrhizal or litter-decomposing basidiomycetes. *New Phytol.*, **134**, 123–132.
6. Dighton, J., Poskitt, J. M. & Howard, D. M. (1986) Changes in occurrence of basidiomycete fruit bodies during forest stand development: with specific reference to mycorrhizal species. *Trans. Br. Mycol. Soc.*, **87,** 163–171.
7. Duchesne, L. C., Peterson, R. L. & Ellis, B. E. (1989) The time course of disease suppression and antibiosis by the ectomycorrhizal fungus *Paxillus involutus. New Phytol.*, **111**, 693–698.
8. Finlay, R. D. & Read, D. J. (1986) The structure and function of the vegetative mycelium of ectomycorrhizal plants. II. The uptake and distribution of phosphorus by mycelial strands interconnecting host plants. *New Phytol.*, **103**, 157–165.
9. Fox, F. M. (1986) Groupings of ectomycorrhizal fungi of birch and pine, based on establishment of mycorrhizas on seedlings from spores in unsterile soils. *Trans. Br. Mycol. Soc.*, **87**, 371–380.
10. Lindahl, B. et al. (1999) Translocation of $^{32}P$ between interacting mycelia of a wood-decomposing fungus and ectomycorrhizal fungi in microcosm systems. *New Phytol.*, **144**, 183–193.
11. Lu, X. et al. (1999) Fruiting of putative ectomycorrhizal fungi under blue gum (*Eucalyptus globulus*) plantations of different ages in Western Australia. *Mycorrhiza,* **8**, 255–261.
12. Meyer, F. H. (1973) Distribution of ectomycorrhizae in native and man-made forests. *In* Ectomycorrhizae: their ecology and physiology, eds. Marks, G. C. & Kozlowski, T. T., Academic Press, New York, 79–105.
13. Nara, K., Nakaya, H. & Hogetsu, T. (2003) Ectomycorrhizal sporocarp succession and production during early primary succession on Mount Fuji. *New Phytol.*, **158,** 193–206.
14. Smits, W. T. M. (1994) Dipterocarpaceae: mycorrhizae and regeneration. The Tropenbos Foundation, Wageningen, Netherlands, pp.243.
15. Tawaraya, K. et al. (2003) Arbuscular mycorrhizal colonization of tree species grown in peat swamp forests of Central Kalimantan, Indonesia. *For. Ecol. Manage.*, **182**, 381–386.
16. Visser, S. (1995) Ectomycorrhizal fungal succession in jack pine stands following wildfire. *New Phytol.*, **129**, 389–401.
17. Vogt, K. A., Grier, C. C. & Vogt, D. J. (1986) Production, turnover, and nutrient dynamics of above and below-ground detritus of world forests. *Adv. Ecol. Res.*, **15**, 303–317.