Fungal succession on woody litter of *Magnolia liliifera* (*Magnoliaceae*)

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Fungal succession (sequential occurrence of sporulating fungi) on wood baits of *Magnolia liliifera* (*Magnoliaceae*) was investigated at Doi Suthep-Pui National Park, Thailand by studying changes in fungal communities on wood placed on the forest floor over a 29 month period of decomposition. Pioneer, mature and impoverished stages comprising distinct fungal communities were observed. A total of 163 sporulating taxa were recorded (114 anamorphic taxa, 46 ascomycetes and 3 basidiomycetes). The observed fungal diversity was high when compared to other studies. The number of fungal species was highest during the mature stage of wood decomposition. Anamorphic fungi were the dominant group on wood baits throughout the experiment. *Lasiodiplodia theobromae* and *Nectria coccinea* were regular inhabitants on wood throughout the study and were found on wood samples up to 10 sampling times. *Canalisporium pallidum*, *Dactylaria hyalina*, *Lasiodiplodia theobromae*, *Nectria coccinea* and *Xylaria carpophila* dominated the fungal communities during the various stages of the decomposition period. *Chloridium botryoideum*, *Dactylaria hyalina*, *Nectria coccinea*, *Volutella ramkumarii* and *Xylaria carpophila* were common overlapping species identified at all three stages of succession. Fungal diversity on naturally occurring samples was higher than on bait samples and overlap of species among them was low.

Key words: fungal succession, lignicolous fungi, *Magnolia*, *Magnoliaceae*

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Introduction

The term "fungal succession" has been defined in various ways. The most acceptable definition of "succession" is that of Rayner and Todd (1979), who defined it as "the sequential occupation of the same site by thalli (normally mycelia) either of different fungi or different associations of fungi". Fungal successsion is a time-related change in fungal community structure (Dix and Webster, 1985). In other words, the study of fungal succession involves analysis of the changes in the structure of fungal communities on various substrata over time (Yanna, 1997; Suzuki, 2002; Paulus *et al*., 2006). To date, most studies on fungal succession have taken a synecological approach, recording species assemblages at different stages of decay (Paulus *et al*., 2006).

Succession of saprobic fungi on decaying plant material has previously been studied in temperate regions (Hudson, 1968; Dickinson and Pugh, 1974; Frankland, 1981; Swift, 1982; Cooke and Rayner, 1984) and most studies have focused at the substratum level (e.g. terrestrial wood: Lange, 1992; rust-infected plum leaves and wheat stems: McKenzie and Hudson, 1976; dung: Nagy and Harrower, 1979; pine cones: Kasai *et al*., 1995 and wool: Ghawana *et al*., 1997). A recent book devoted

to fungal succession (Hyde and Jones, 2002) included 16 papers dealing with various aspects of fungal succession and includes 11 papers presenting studies on succession of microfungi on various decaying substrata in temperate and particularly in subtropical and tropical regions (e.g. Promputtha *et al*., 2002; Sivichai *et al*., 2002; Somrithipol *et al*., 2002; Suzuki, 2002; Tokumasu and Aoiki, 2002; Yanna *et al*., 2002; Zhou and Hyde, 2002). More recently, studies of fungal succession have been carried out in the tropics and subtropics (Sandhu and Sidhu, 1980; Fryar *et al*., 2004; Tang *et al*., 2005; Paulus *et al*., 2006).

There have been some studies on fungal succession in Thailand. Promputtha *et al*. (2002) reported on fungal succession on leaves of *Magnolia liliifera* and Somrithipol *et al*. (2002) reported on fungal succession on fruits and seeds of *Delonix regia* exposed on a natural forest floor. Sivichai *et al*. (2002) studied the succession of fungi on wood of *Dipterocarpus alatus* and *Xylia dolabriformis* exposed in a freshwater stream. Duong *et al*. (2008) reported on fungal succession on *Castanopsis diversifolia* leaves and Thong-kantha *et al*. (2008) on leaves of *Pandanus penetrans*.

There have been several studies of fungal succession on wood worldwide (e.g. Ho *et al*., 2002; Kane *et al*., 2002; Panebianco *et al*., 2002; Sivichai *et al*., 2002), however, only a few have focused on terrestrial wood. In this paper, the sequential occurrence of sporulating fungi on woody litter of *Magnolia liliifera* in Doi Suthep-Pui National Park, northern Thailand was studied. The principal aims of this study were to 1) evaluate fungal diversity on *Magnolia liliifera* wood in terms of the composition of fungal communities during the decay process, and 2) study the sequential occurrence of fungi over a 29-month period of wood decomposition to establish species richness at different stages of wood decomposition until the wood had completely decayed.

Materials and methods

Study site

Details of the experimental site at Doi Suthep-Pui National Park, Chiang Mai, Thailand have been described in Kodsueb *et al*. (2008).

Bait preparation for study of terrestrial succession

Two-hundred living samples (sample size ~ 30 cm long, varying in diameter from 1 cm to 2.5 cm, with bark) of *Magnolia liliifera* were cut and collected from living trees growing in Doi Suthep-Pui National Park. Samples were oven-dried at 70°C for one week and tied with labelled plastic tags (Fig. 1). Dried samples (baits) were then placed on the ground under *M. liliifera* trees on 9 July 2002 (Fig. 2). Ten baits were randomly collected from the field at each sampling time. It was planned to collect samples at day 15, months 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, 31, 33 and 35. However, at month 23, some wood samples had completely decayed. Therefore, wood samples were only collected on 24 July 2002 (Day 15) until 04 January 2005 (Month 29) (Table 3). Samples were placed in separate plastic bags in the forest and taken back to the laboratory. Soil and any leaves were removed from the samples. Sterile moist tissue paper was added to create a damp chamber within the bags. All of the wood samples were examined under stereo and compound microscopes for the presence of microfungi after a three-day incubation period and then periodically for up to one month. Squash mounts of sporulating fungi were made in water for examination with differential interference contrast microscopy and mounted in lactophenol/lactoglycerol and sealed with nail varnish for semi-permanent slides. Herbarium specimens of selected fungi were prepared and dried in an oven at 37ºC for one week and deposited in Chiang Mai University (CMU) Herbarium.

Collection of samples to investigate naturally occurring fungi

During the experimental period, naturally occurring litter of *Magnolia liliifera* were collected on 09 July 2002, 21 April 2003 and 29 April 2006 for comparison with the litter baits. At each sampling time, wood samples were collected (in total 60 samples, sample size~ 30 cm long, varying in diameter from 1 cm to 2.5 cm, with/without bark), examined and stored as described for the bait samples.

Fig. 1. Oven-dried *Magnolia liliifera* wood samples tied with labeled plastic tags before placement at the experimental sites.

Fig. 2. Wood samples of *Magnolia liliifera* placed on the ground under *M. liliifera* trees.

Statistical analysis

A 3-dimensional correspondence analysis (JMP) was performed to examine the differences in fungal communities at different times of decay (Anonymous, 1995).

The results of this study are presented in terms of percentage occurrence of fungi. Fungal taxa with a percentage occurrence equal to or higher than 10 are regarded as dominant species. These fungal taxa were used to plot changes in the dominant species throughout the experimental period. Shannon indices (H') were used to express species diversity of a community (Shannon and Weaver, 1949), while species accumulation curves were used to determine the adequacy of the sampling size. The relative similarities of microfungal assemblages from woody litter at different stages of decomposition were identified by cluster analysis. A cluster dendrogram was produced from PC-ORD version 4.0 (McCune and Mefford, 1999). Calculations were based on Sørensen distance and group average as the cluster distance measure and linkage method, respectively.

$$\text{Percentage occurrence} = \frac{\text{Number of wood samples on which each fungus was detected}}{\text{Total number of wood samples examined}} \times 100$$

$$\text{Shannon index (H')} = - \Sigma \, Pi \log_2 Pi$$

Where Pi is the probability of finding each taxon in a collection.

Results

A total of 140 wood bait samples of *Magnolia liliifera* were examined for saprobic fungi with 701 identifications and 163 taxa identified over the experimental period. The taxa and their percentage occurrences are listed

Table 1. Frequency and overall percentage occurrence of fungal taxa on *Magnolia liliifera* wood during the decay process. Ten wood samples examined at each time.

Taxa	Sampling time (day 15 to month 29)														Total	Overall % occurrence
	D15	M1	M3	M5	M7	M9	M11	M13	M15	M17	M19	M21	M23	M29		
Acanthophyses-like structure		1													1	0.7
Acremonium sp.	8	3		1		1									13	9.3
Acrogenospora sphaerocephala													1		1	0.7
Anthostomella sp.								1							1	0.7
Aquaphila albicans	3														3	2.1
Aquaticola ellipsoidea											1	1			2	1.4
Arthrobotrys sp.						1	2								3	2.1
Bactrodesmium longispora										1					1	0.7
Bactrodesmium ramosius										1					1	0.7
Basidiomycete sp. 1							1								1	0.7
Basidiomycete sp. 2														1	1	0.7
Berkleasmium concinnum			1	6		3									10	7.1
Bionectria sp.														1	1	0.7
Bisporomyces lignicola		1	1												2	1.4
Bitunicate Ascomycete										1					1	0.7
Boerlagiomyces grandisporus								**1**	**4**	**3**	**4**	**1**	**3**		**16**	**11.4**
Canalisporium caribense								**3**	**6**	**5**					**14**	**10**
Canalisporium cf. *caribense*							4		1						5	3.6
Canalisporium exiguum											1				1	0.7
Canalisporium pallidum					**1**						**9**	**8**	**6**		**24**	**17.1**
Canalisporium sp. 1													1		1	0.7
Canalisporium sp. 2				2											2	1.4
Candelabrum sp.								1					2		3	2.1
***Coprinus* sp.**			**2**	**1**		**1**	**3**	**3**	**2**		**1**	**1**	**2**		**16**	**11.4**
Catenularia malabarica											1	1	1		3	2.1
Cercophora arenicola					1										1	0.7
Cercophora sp.														2	2	1.4
Cercospora sp.										1					1	0.7
Cercosporella sp.	1														1	0.7
Chaetomium globosum		3	5		1										9	6.4
Chaetopsina fulva			1												1	0.7
Chalara hyalina												1			1	0.7
Cheiromyces sp.									1						1	0.7

Note: Bold indicates percentage occurrence of more than 10% (dominant taxa).

Table 1 (continued). Frequency and overall percentage occurrence of fungal taxa on *Magnolia liliifera* wood during the decay process. Ten wood samples examined at each time.

Taxa	Sampling time (day 15 to month 29)														Total	Overall % occurrence
	D15	M1	M3	M5	M7	M9	M11	M13	M15	M17	M19	M21	M23	M29		
Chloridium botryoideum				2									1	3	6	4.3
Chloridium lignicola							1								1	0.7
Chloridium sp.			1												1	0.7
Chloridium viride							**5**	**5**	**1**	**4**	**4**	**3**			**22**	**15.7**
Clonostachys cylindrospora	1	1			1				1						4	2.9
Coelomycete sp.									1						1	0.7
Corynespora cassiicola	5	2		3		2									12	8.6
Cryptophiale udagawae													1		1	0.7
Cryptophialoidea unilateralis												1			1	0.7
Cylindrocarpon candidum	4	5	1												10	7.1
***Cylindrocladium* sp.**			**5**		**1**	**1**					**1**	**5**	**1**		**14**	**10**
Dactylaria biseptata	**1**	**3**	**3**	**3**	**4**	**1**		**3**			**1**				**19**	**13.6**
Dactylaria cf. *lakebarrinensis*							3		1	1		6	1		12	8.6
Dactylaria hyalina		**2**	**2**			**1**	**1**		**3**		**4**	**2**	**7**	**2**	**24**	**17.1**
Dactylaria irregularis											1				1	0.7
Dactylaria longidentata											1				1	0.7
Dactylaria sp.														1	1	0.7
Dactylaria sp. grouped spore													1		1	0.7
Dactylella sp. 1	3														3	2.1
Dactylella sp. 2					3										3	2.1
Daldinia concentrica								1							1	0.7
Diatrypella quercina									1						1	0.7
Dictyochaeta australiensis									1				2		3	2.1
Dictyochaeta simplex				1											1	0.7
Dictyochaeta sp.													2		2	1.4
Dictyochaeta uliginicola								1	3						4	2.9
Dictyosporium heptasporum						2									2	1.4
Dictyosporium subramanianii				1	1										2	1.4
Dischloridium regenerans									1						1	0.7
Dischloridium sp.										1					1	0.7
Discomycete sp.												1			1	0.7

Note: Bold indicates percentage occurrence of more than 10% (dominant taxa).

Table 1 (continued). Frequency and overall percentage occurrence of fungal taxa on *Magnolia liliifera* wood during the decay process. Ten wood samples examined at each time.

Taxa	Sampling time (day 15 to month 29)														Total	Overall % occurrence
	D15	M1	M3	M5	M7	M9	M11	M13	M15	M17	M19	M21	M23	M29		
Discomycetoidea aequatorialis	2														2	1.4
Ellisembia adscendens			1	1	6	3		1							12	8.6
Ellisembia brachypus				2		3	1								6	4.3
Ellisembia sp. 1											1				1	0.7
Ellisembia sp. 2											1				1	0.7
Eutypa sp.									1						1	0.7
Exosporium ampullaceum						1									1	0.7
Fusarium sp. 1		1													1	0.7
Fusarium sp. 2												2			2	1.4
Gliocladium sp.	3	4			1										8	5.7
Gonytrichum macrocladum				**1**		**1**		**3**	**4**	**3**	**3**	**3**	**2**		**20**	**14.3**
Guignardia sp.	1	1													2	1.4
Helicomyces macrofilamentosus											1				1	0.7
Helicomyces roseus						2									2	1.4
Helicomyces sp.						1									1	0.7
Helicosporium aureum					1										1	0.7
Helicosporium vegetum							1		1		1				3	2.1
Henicospora longissima										1			1		2	1.4
Henicospora sp.									1						1	0.7
Hilberina caudata														1	1	0.7
Hyalosynnema magnoliae sp. nov.				1								1	1		3	2.1
Hyphomycete sp.														1	1	0.7
Hypoxylon fragiforme						1									1	0.7
Hypoxylon sp.										1			1		2	1.4
Lasiodiplodia theobromae	**10**	**8**	**4**	**9**	**7**	**6**	**4**	**7**	**2**	**1**	**1**		**1**		**60**	**42.9**
Lasiosphaeria sp.												1			1	0.7
Melanocephala australiensis													1		1	0.7
Melanocephala cupulifera							2	1							3	2.1
Melanocephala sp.									1	1					2	1.4
Melanochaeta hemipsila							3	1			1		1		6	4.3
Mirandina dactylelloides				4											4	2.9
Monacrosporium sp.														1	1	0.7
Monodictys peruviana										1					1	0.7

Note: Bold indicates percentage occurrence of more than 10% (dominant taxa).

Table 1 (continued). Frequency and overall percentage occurrence of fungal taxa on *Magnolia liliifera* wood during the decay process. Ten wood samples examined at each time.

Taxa	Sampling time (day 15 to month 29)														Total	Overall % occurrence
	D15	M1	M3	M5	M7	M9	M11	M13	M15	M17	M19	M21	M23	M29		
Monodictys sp.						1									1	0.7
Mycosphaerella sp.											2				2	1.4
Nakataea serpens														1	1	0.7
Nakataea sp.									1						1	0.7
Nectria aureo-fulva			1												1	0.7
Nectria coccinea	**8**	**7**	**9**	**3**	**3**	**3**	**4**	**7**	**4**	**3**				**1**	**52**	**37.1**
Nectria galligena						2	2					1			5	3.6
Nectria sp.									1						1	0.7
Nectriella cf. *microspora*	1														1	0.7
Nectriopsis sp.									2	1		2	1		6	4.3
Neta compacta												1			1	0.7
Neta sp.											1				1	0.7
Nodulisporium sp.								1							1	0.7
Ophioceras sp.					1										1	0.7
Ophiochaeta lignicola				1											1	0.7
Orbilia xanthostigma														1	1	0.7
Paecilomyces sp.					1										1	0.7
Penicillium sp.		1													1	0.7
Periconiella sp. 1							1								1	0.7
Periconiella sp. 2										1					1	0.7
Phaeoisaria clematidis	2				1		1	1							5	3.6
Phaeosphaeria sp. 1						1									1	0.7
Phaeosphaeria sp. 2							2								2	1.4
Phaeostalagmus rossicus	**5**	**3**	**1**		**5**	**1**		**1**	**4**	**1**					**21**	**15**
Phoma sp.	1														1	0.7
Phomopsis sp.											1				1	0.7
Pleurocatena acicularis												1			1	0.7
Pleurothecium recurvatum			1												1	0.7
Pseudobotrytis terrestris												1			1	0.7
Ramichloridium fasciculatum										1					1	0.7
Ramichloridium lignicola												1			1	0.7

Note: Bold indicates percentage occurrence of more than 10% (dominant taxa).

Table 1 (continued). Frequency and overall percentage occurrence of fungal taxa on *Magnolia liliifera* wood during the decay process. Ten wood samples examined at each time.

Taxa	Sampling time (day 15 to month 29)														Total	Overall % occurrence
	D15	M1	M3	M5	M7	M9	M11	M13	M15	M17	M19	M21	M23	M29		
Rhinocladiella mansonii							2								2	1.4
Rhinocladiella sp.						1									1	0.7
Scolecobasidium sp.							1								1	0.7
Spadicoides magnoliae		1						1			1				3	2.1
Sporidesmium sp. 1				1		1									2	1.4
Sporidesmium sp. 2								1							1	0.7
Sporoschisma saccardoi				1	1		4	2			1	1	1		11	7.9
Sporothrix sp.											2				2	1.4
Stibella sp.								1							1	0.7
Stilbohypoxylon quisquiliarum							1	3							4	2.9
Tapesia fusca												1			1	0.7
Torula herbarum	1														1	0.7
Trichoderma lignorum				2	1										3	2.1
Trichoderma viride							1			1					2	1.4
Tubeufia cylindrothecia							1								1	0.7
Tubeufia paludosa										1					1	0.7
Unitunicate Ascomycete sp. 1					2	2									4	2.9
Unitunicate Ascomycete sp. 2									1						1	0.7
Veronaea botryosa									1						1	0.7
Verticillium sp. 1		1	4	1	2										8	5.7
Verticillium sp. 2							2				1		2		5	3.6
Verticillium sp. 3														4	4	2.9
Verticillium tenerum								1							1	0.7
Volutella ramkumarii						2				1				1	4	2.9
Xylaria carpophila		**3**	**3**	**6**	**6**	**4**	**5**	**1**				**4**		**1**	**33**	**23.6**
Xylaria filiformis								**4**	**2**	**2**	**3**		**4**		**15**	**10.7**
Xylaria hypoxylon							1								1	0.7
Xylaria longipes									1						1	0.7
Xylaria magnoliae							1								1	0.7
Xylaria polymorpha								4					3		7	5
Xylaria sp. 1								1							1	0.7
Xylaria sp. 2								1							1	0.7
Xylaria sp. 3										1					1	0.7
Xylaria sp. 4													1		1	0.7
Xylomyces aquaticus										1					1	0.7

Note: Bold indicates percentage occurrence of more than 10% (dominant taxa).

in Table 1. Anamorphic fungi (114 taxa) were the dominant group, followed by ascomycetes (46) and basidiomycetes (3) (Table 3). Most of the genera (55.6%) collected in this study are represented by a single species and collected only once. The overall dominant species were *Lasiodiplodia theobromae* (42.7%), *Nectria coccinea* (37.1%), *Xylaria carpophila* (23.6%), *Dactylaria hyalina* (17.1%), *Canalisporium pallidum* (17.1%), *Chloridium viride* (15.7%), *Phaeostalagmus rossicus* (15%), *Gonytrichum macrocladum* (14.3%), *Dactylaria biseptata* (13.6%), Basidiomycete sp. 1 (11.4%), *Boerlagiomyces grandisporus* (11.4%), *Xylaria filiformis* (10.7%), *Cylindrocladium* sp. (10%) and *Canalisporium caribense* (10%). *Lasiodiplodia theobromae* and *Nectria coccinea* were regular inhabitants on wood throughout the study (found on wood samples up to 10 sampling times). Of the 96 genera (including taxa that could be identified to genus level only) recorded in this study, only 32% (31 genera) have been previously recorded from magnoliaceous hosts (see Kodsueb *et al*., 2008 for details).

Succession at different stages of decay

Three-dimensional correspondence analysis (Fig. 3) of fungal communities showed that there were three distinct succession communities; the pioneer community (day 15-month 9), the mature community (months 11-23) and the impoverished community (Month 29). Although fungal communities were distinct at each stage of succession, the dominant species partially overlapped between succession stages (Fig. 4).

Species richness, Shannon diversity index, Simpson's diversity index and species evenness obtained from cluster analysis using PC-ORD Version 4.0 are presented in Table 2. Species richness increased from 18 to 27 taxa during the pioneer community, plateaued at 25-29 during the mature community and was lowest at 15 during the impoverished community. Shannon diversity index accounts for abundance of species present (Duong *et al*., 2008). The index increases as unique species number or species evenness increases (http://en.wikipedia.org/wiki/Shannon_index).

The values increased from 2.6 at the beginning of the study and reached a peak of about 3.1 at month 11-15, then gradually declined until month 29. Simpson's diversity index (referred to as dominance measures) also measures species diversity in a community, however, it is heavily weighted towards the most abundant species in the sample while being less sensitive to species richness (Magurran, 1988). Species evenness measures the relative abundance of each species. These two latter indices changed little throughout the decay process.

The analysis of the similarity of fungi using cluster analysis generated a dendogram, which separated into three groups (Fig. 5) and corresponded with the 3D-correspondence analysis (Fig. 3).

Species richness and dominant taxa during stages of succession

During the pioneer stage (day 15-month 9) 65 fungal taxa were identified and *Dactylaria biseptata*, *Lasiodiplodia theobromae*, *Nectria coccinea*, *Phaeostalagmus rossicus* and *Xylaria carpophila* were dominant. *Lasiodiplodia theobromae* had the highest frequency of occurrence (42.9%). During the mature community (months 11-23) the number of species was highest (113 taxa) and were represented by many taxa with low percentage occurrence (most of them a single record). The dominant taxa comprised Basidiomycete sp. 2, *Boerlagiomyces grandisporus*, *Chloridium viride*, *Dactylaria hyalina*, *Gonytrichum macrocladum*, *Lasiodiplodia theobromae*, *Nectria coccinea* and *Xylaria filiformis*. During the impoverished stage, the diversity and number of taxa declined. Dominant taxa were *Dactylaria hyalina*, *Nectria coccinea* and *Xylaria carpophila*. Twenty-one taxa were identified as common to both the pioneer and mature stages, while *Chloridium botryoideum*, *Dactylaria hyalina*, *Nectria coccinea*, *Volutella ramkumarii* and *Xylaria carpophila* were identified at all three stages of succession.

Comparison between fungal communities on naturally occurring woody litter and baits

The taxa obtained from naturally occurring terrestrial samples were somewhat similar

Table 2. Diversity indices of saprobic fungi recovered from *Magnolia liliifera* wood during the succession study.

Sampling time	Diversity indices			
	Richness (S)	Evenness (E)	Shannon's diversity index (H)	Simpson's diversity index (D)
D15	18	0.894	2.584	0.9067
M1	19	0.915	2.695	0.9173
M3	18	0.901	2.604	0.9064
M5	22	0.904	2.796	0.9206
M7	22	0.904	2.793	0.9227
M9	27	0.947	3.120	0.9471
M11	28	0.946	3.153	0.9506
M13	29	0.918	3.091	0.9422
M15	29	0.937	3.154	0.9479
M17	26	0.941	3.067	0.9425
M19	27	0.909	2.997	0.9304
M21	25	0.906	2.918	0.9281
M23	28	0.927	3.089	0.9408
M29	15	0.946	2.563	0.9091
Average	**23.8**	**0.921**	**2.902**	**0.9295**

to those obtained from the baits, however, they differed in terms of richness and frequency of occurrence. Naturally occurring wood samples had slightly higher species richness than the baits (82 taxa from 60 samples vs. 163 taxa from 140 samples). The dominant species from naturally occurring samples comprised *Anthostomella ludoviciana* (16.7%), *Brachydesmiella caudata* (13.3%), *Canalisporium caribense* (16.7%), *Corynespora cassiicola* (60%), *Diaporthe* sp. 2 (16.7%), *Ellisembia adscendens* (10%), *E. brachyphus* (11.7%), *Massarina* sp. (13.3%), *Nectria coccinea* (10%), *Phaeoisaria clematidis* (20%), *Phoma* sp. (10%), *Phomopsis* sp. (11.7%), *Sporidesmium* sp. 1 (13.3%) and *Verticillium* sp. (10%). Thirty-four species occurred on both the baits and on the naturally fallen woody litter (Table 4). The dominant species of fungi on *Magnolia liliifera* woody litter and on baits is compared in Table 5.

Discussion

Fungal diversity

This is one of a few studies on fungi on decaying terrestrial wood in the tropics and is the first study that addresses fungal succession of terrestrial wood in the tropics. The only comparable study is that of Huhndorf and Lodge (1997) who investigated pyrenomycetes on 30 species of decaying wood in Puerto Rico and Thienhirun (1997) and Chatanon (2001) who investigated ascomycetes on decaying wood in Thailand. Studies on fungal succession in the tropics have either addressed fungi on submerged wood in streams or the sea (Ho *et al*., 2002; Sivichai *et al*., 2002; Maria and Sridhar, 2004) or on leaf litter (Tang *et al*., 2005; Duong *et al*., 2008; Thongkantha *et al*., 2008).

In this study we investigated the fungal diversity on *Magnolia liliifera* and identified 163 species from 140 samples, which is high when compared with other studies. Fewer species occur on submerged wood (Tsui *et al*., 2000; Sivichai *et al*., 2002; Maria and Sridhar, 2004) and leaves (Duong *et al*., 2008; Thongkantha *et al*., 2008). The higher diversity on wood may result from the longer decomposition period when compared with leaves (Table 6), while lower numbers on wood submerged in freshwater may result from fewer fungi being adapted for a submerged lifestyle. Wood decays slowly because of its recalcitrant properties (Boddy, 1986). This has resulted in some fungi developing antagonistic and competitive abilities so they can grow successfully on wood alongside other taxa (Shearer, 1992; Fryar *et al*., 2004). Wood also has a larger volume than leaves. These two effects may be responsible for the higher diversity of fungi on decaying wood as compared to leaves (Promputtha *et al*., 2002). Most previous succession studies focused on leaf litter rather

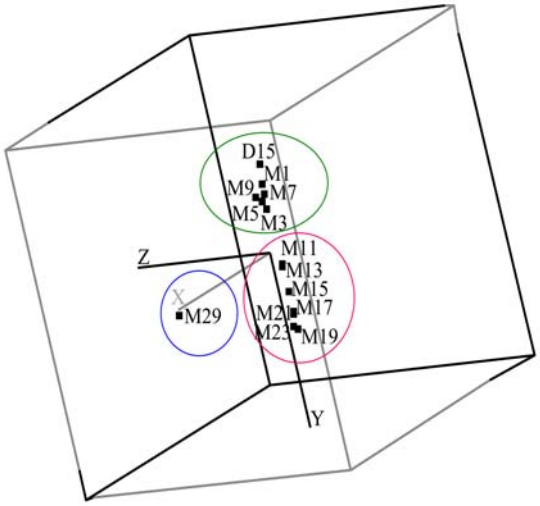

Fig. 3. 3D-correspondence analysis of fungal succession on woody litter of *Magnolia liliifera*.

Table 3. Date of collection and number of fungi found from each sampling time during the succession study.

Sampling time	Date of collection	Number of fungi found on each sampling time			
		Anamorphic fungi	Ascomycetes	Basidiomycetes	Total
D15	24/07/2002	15	3	0	18
M1	09/08/2002	15	4	0	19
M3	24/10/2002	13	4	1	18
M5	11/12/2002	18	3	1	22
M7	10/02/2003	16	6	0	22
M9	08/04/2003	20	6	1	27
M11	08/06/2003	17	9	2	28
M13	10/08/2003	17	11	1	29
M15	15/10/2003	18	9	2	29
M17	11/12/2003	18	8	0	26
M19	14/02/2004	19	5	1	25
M21	05/04/2004	16	8	1	25
M23	04/06/2004	20	7	1	28
M29	04/01/2005	8	6	1	15

than woody litter. Generally, the composition of wood is quite different from other plant litter (i.e. leaves) with woody litter having high lignocellulose and low nitrogen content (Wong *et al*., 1998). Only few groups of fungi possess enzymatic capabilities to digest wood (Tubaki, 1958; Singh, 1982; Zare-Maivan and Shearer, 1988; Abdullah and Taj-Aldeen, 1989; Bucher *et al*., 2004) and this may also account for the fact that fungi on woody litter are different to those on leaf litter.

Fungal communities at different decaying stages of terrestrial wood baits

During succession the fungal communities have usually clustered into three stages of decay: early or pioneer, middle or intermediate or mature, and late or impoverished stage (Paulus *et al*., 2006: Duong *et al*., 2008; Thongkantha *et al*., 2008). In our study the fungal communities also clustered into three stages of decay.

Tan *et al*. (1989) and Maria and Sridhar (2004) studied colonization of fungi on mangrove wood and reported the highest number of species during the mature stage of wood decomposition. Several observations on Norway spruce logs also provided the same result (Niemelä *et al*., 1995; Renvall, 1995; Linbald, 1998). In accordance with the results from fungal succession studies, Tiwari *et al*. (1994) and Yanna *et al*. (2002) found that the number of species of fungi was maximum during the mature stage of decomposition of palm fronds and pineapple leaves. In the present study the highest number of fungal species occurred during months 13-15 of exposure (29 species recovered), also supporting earlier observations. Tiwari *et al*., (1994) also found that species diversity peaked during the mature stage of decomposition and that weight loss at this period was highest.

Anamorphic fungi were the dominant group in this study and this is also in agreement with previous studies. (i.e. Leung, 1998; Zhou and Hyde, 2002). Wood samples are almost completely decayed by the impoverished stage of decomposition. Thus few species of fungi were present, with those present having a high occurrence (Table 1). *Verticillium* sp. 3 and *Cercophora* sp. were only found during this impoverished stage. Basidiomycete species are believed to dominate over ascomycetes during the later stages of decomposition of leaves (Duong *et al*., 2008), since they can synthesize the enzymes required to degrade complex polymers such as lignin (Deacon, 1997). Three basidiomycetes were recorded in this study (Table 1), *Coprinus* sp. was recorded throughout most of the pioneer and mature stages. Basidiomycete sp. 2 was found only during the mature stage, while Basidiomycete sp. 3, was found only during the impoverished stage. The reasons for the difference in occurrence of these basidiomycetes are still unclear and needs further study.

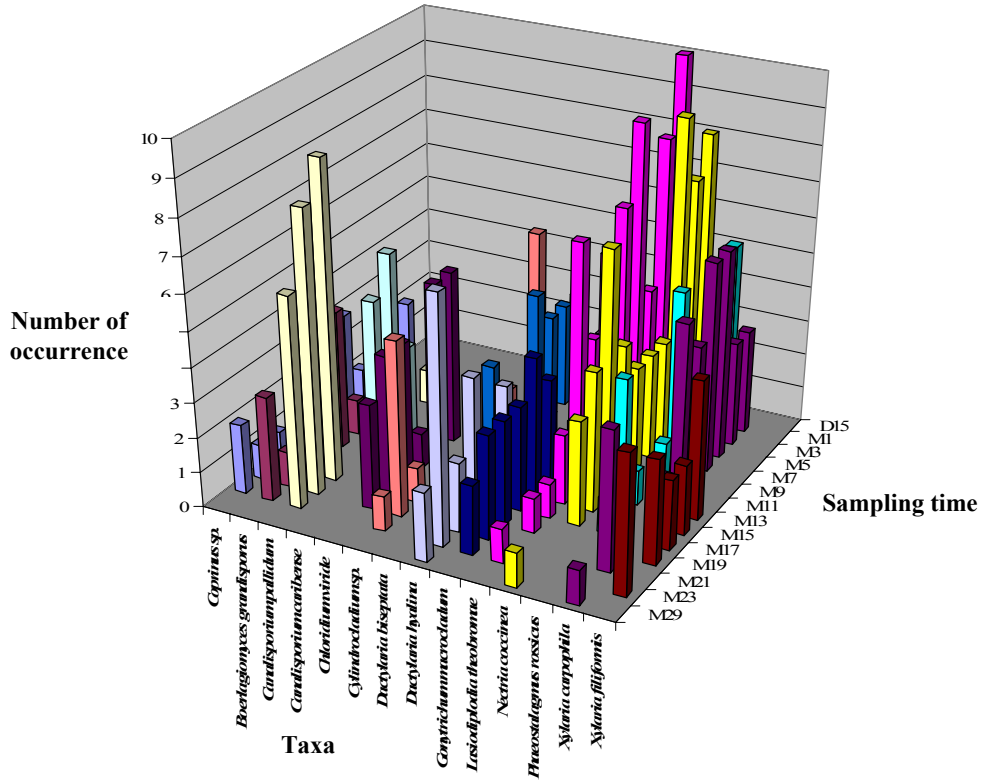

Fig. 4. Succession patterns of dominant fungi on wood of *Magnolia liliifera* throughout the experimental period.

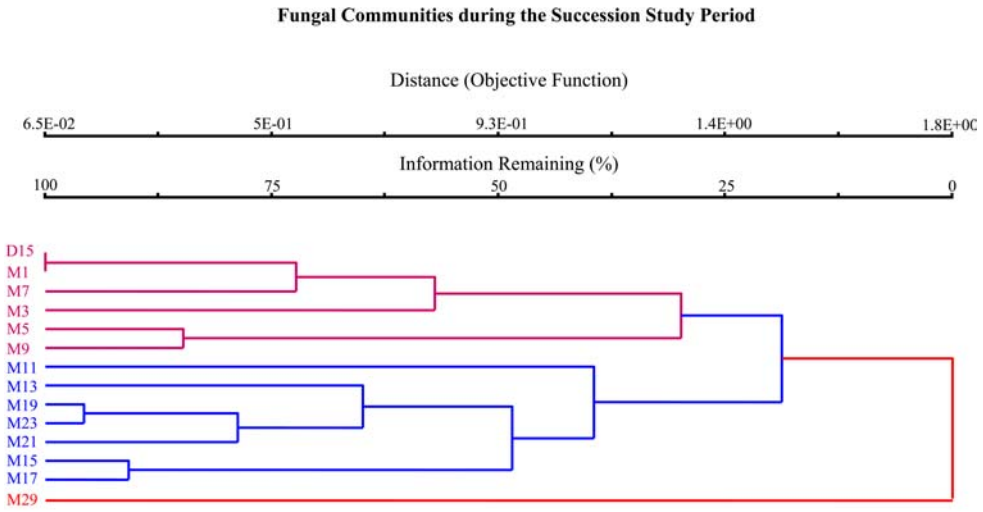

Fig. 5. Cluster analysis of saprobic fungi on *Magnolia liliifera* woody litter based on Sørensen distance and the group average method.

Fungal communities on baits versus those on naturally decaying samples

Fungal diversity on submerged baits has been found to be greater than on naturally submerged wood (Sivichai *et al*., 2000; Kane *et al*., 2002; Sivichai *et al*., 2002). In the present study we found that the terrestrial baits had a lower species richness than naturally occurring terrestrial samples. This is in agreement with the result of studies on leaves of *Berchemia floribunda*, *Magnolia liliifera*, and *Meliosma simplicifolia* where the number of fungal taxa obtained from leaf baits in those studies was less than naturally occurring leaf samples (Promputtha, pers. comm.). The reason is possibly due to a mixture of ages in natural samples. A study of saprobic fungi on terrestrial *Phoenix hanceana* in Hong Kong showed that the similarity between fungi occurring on leaf baits and naturally occurring palm leaves is low (Yanna *et al*., 2002) and this is also true in the present study where only 34 taxa overlapped between the two sample types (similarity index is 0.28; Table 4: see Kodsueb *et al*., 2008 for calculation formula).

Table 4. Fungal species found on both wood baits and on naturally fallen woody litter of *Magnolia liliifera*.

Taxa	
Aquaticola ellipsoidea	*Ophiochaeta lignicola*
Basidiomycete sp. 2	*Penicillium* sp.
Canalisporium caribense	*Phaeoisaria clematidis*
Canalisporium pallidum	*Phaeosphaeria canadensis*
Cercophora sp.	*Phaeosphaeria* sp.
Coprinus sp.	*Phoma* sp.
Corynespora cassiisola	*Phomopsis* sp.
Dactylaria hyalina	*Sporidesmium* sp. 1
Discomycete sp.	*Sporoschisma saccardoi*
Ellisembia adscendens	*Stibella aciculosa*
Ellisembia brachyphus	*Stilbohypoxylon quisquiliarum*
Ellisembia sp.	*Tubeufia cylindrothecia*
Gonytrichum sp.	*Tubeufia paludosa*
Helicosporium vegetum	Unitunicate ascomycete sp. 1
Hyphomycete sp.	Unitunicate ascomycete sp. 2
Melanochaeta hemipsila	*Verticillium* sp.
Nectria coccinea	*Volutella ramkumarii*

Succession of fungi on terrestrial Magnolia liliifera wood baits versus those on other terrestrial wood samples

A succession of fungi during the process of decomposition on plant litter has been observed in a variety of plant species in terrestrial ecosystems (Carre, 1964; Frankland, 1966; Saitô, 1966; Swift, 1976; Tokumasu *et al*., 1994; Kasai *et al*., 1995; Heilmann-Clausen, 2001; Lumley *et al*., 2001; Paulus *et al*., 2006). Fungal succession on wood has also been well-studied, however, most studies have focused on aquatic habitats; freshwater or marine (Tan *et al*., 1989; Hyde, 1991; Leong *et al*., 1991; Ho *et al*., 2002; Kane *et al*., 2002; Sivichai *et al*., 2002; Fryar *et al*., 2004; Maria and Sridhar, 2004; Van Ryckegem and Verbeken, 2005) or terrestrial wood in temperate regions (Crites and Dale, 1998; Allen *et al*., 2000).

The fungi occurring on wood of *M. liliifera* and other wood in terrestrial ecosystems are dissimilar with little overlap of species (Hunhdorf and Lodge, 1997; Chatanon, 2001), although overlap of gerera is common. For example, *Anthostomella*, *Ascotaiwania*, *Cercophora*, *Chaetosphaeria*, *Diatrype*, *Didymosphaeria*, *Eutypa*, *Hypoxylon*, *Melanochaeta*, *Nectria*, *Stilbohypoxylon*, *Tubeufia* and *Xylaria* occurred in the present study and in other studies (Huhndorf and Lodge, 1997; Thienhirun, 1997; Chatanon, 2001). *Lasiodiplodia theobromae*, *Nectria coccinea* and *Dactylaria hyalina* however, have not been recorded as dominant fungi in other studies. Soil fungi e.g., *Chalara*, *Chloridium*, *Cylindrocladium*, *Dictyochaeta*, *Gliocladium*, *Gonytrichum*, *Periconia*, *Trichoderma* and *Volutella* (Farr, 1989), were also found on decaying wood in the present study.

Several studies have shown that different fungal communities occur in temperate and tropical habitats although several studies have concluded that many freshwater fungi on leaves are cosmopolitan and can be found in both temperate and tropical regions (Wood-Eggenschwiler and Bärlocher, 1985; Goh and Hyde, 1996; Wong *et al*., 1998; Ho *et al*., 2001; Kane *et al*., 2002). Some fungi are, however restricted to specific geographical areas in temperate or tropical regions. Fungi on submerged wood from temperate regions can grow at 25°C, but they are unable to grow as fast as tropical species and this probably

Table 5. Comparison of the dominant species of fungi found on naturally fallen woody litter of *Magnolia liliifera* and on wood baits.

Taxa from naturally fallen litter	% occurrence	Taxa from wood baits	% occurrence
Anthostomella ludoviciana	16.7	*Boerlagiomyces grandisporus*	11.4
Brachydesmiella caudata	13.3	*Canalisporium caribense*	10
Canalisporium caribense	16.7	*Canalisporium pallidum*	17.1
Corynespora cassiicola	60	*Chloridium viride*	15.7
Diaporthe sp. 2	16.7	*Coprinus* sp.	11.4
Ellisembia adscendens	10	*Cylindrocladium* sp.	10
E. brachyphus	11.7	*Dactylaria biseptata*	13.6
Massarina sp.	13.3	*Dactylaria hyalina*	17.1
Nectria coccinea	10	*Gonytrichum macrocladum*	14.3
Phaeoisaria clematidis	20	*Lasiodiplodia theobromae*	42.9
Phoma sp.	10	*Nectria coccinea*	37.1
Phomopsis sp.	11.7	*Phaeostalagmus rossicus*	15
Sporidesmium sp. 1	13.3	*Xylaria carpophila*	23.6
Verticillium sp.	10	*Xylaria filiformis*	10.7

Table 6. Comparison of wood and leaves* (Source: Table 4.1; Shearer, 1992).

Characteristics	Wood	Leaves
A. Physical—chemical features		
C:N ratio	High	Low
Pectins	Low	High
Parenchyma:sclerenchyma ratio	Low	High
Density	High	Low
Surface: volume ratio	Low	High
Size	Varied	Uniform
Input	Episodic	Seasonal
Residence time	Long	Short
B. Fungal Community Dynamics		
Initial colonization	Deterministic	Stochastic
Colonization pattern	Successive	Parallel
Successive communities	Several	Few
Functional group diversity	High?	Low?
Taxonomic diversity	High?	Low?
Competition	High	Low
Interdependence	High?	Low?
Teleomorph:anamorph ratio	High	Low
Grazer/fungal interactions	Low?	High
Rate of decomposition	Slow	Fast

*Characteristics vary among both wood and leaf species; the above comparisons are based on generalized relative differences between wood and leaves.

accounts for their absence in tropical streams (Yuen *et al*., 1998).

The taxa obtained in the present study are more similar to tropical fungi than to those of temperate regions. Huhndorf and Lodge (1997) studied fungi on 30 species of wood in tropical Puerto Rico but only two species, *Melanochaeta hemipsila* and *Tubeufia cylindrothecia*, overlapped although overlapping genera included *Acanthostomella*, *Boerlagiomyces*, *Cercophora*, *Hypoxylon*, *Lasiosphaeria*, *Nectria*, *Stilbohypoxylon* and *Xyalria*. Chatanon (2001) reported 36 species of ascomycetes from terrestrial wood in Huai-Kha-Khaeng wildlife sanctuary, Thailand. Again only two species; *Eutypella stellulata* and *Xylaria polymorpha*, overlapped with the present study. No overlapping species were observed when compared with fungi from decaying wood in temperate regions, and only one genus' *Hypoxylon*, overlapped with this study (Crites and Dale, 1998; Allen *et al*., 2000).

Decomposition rate of substrate vs. number of fungi

The time taken for decomposition of plant litter varies in different regions (Kane *et al*., 2002; Yanna *et al*., 2002; Tang *et al*., 2005). A slow rate of decomposition of plant litter in temperate region is observed and accepted by several studies (Frankland, 1966, 1998; Osono and Takeda, 2001). Conversely, decomposition rate of plant substrate in tropics is generally more rapid (Tang *et al*., 2005). The number of fungi obtained from several succession studies appears to differ dependant on the host species and the period of decomposition (which varies mainly depending on the litter type). Decomposition of woody litter differs between different species and age (Kodsueb, pers. obs.). For instance, wood samples of *Fagus sylvatica* and *Pinus sylvestris* in temperate regions needed more than 92 weeks submergence for total decay (Kane *et al*., 2002). Beech logs in Denmark took 10 to more than 28 years to completely decay on forest floor (Lange, 1992). While in tropics, *Machilus velutina* and *Pinus massoniana* wood needed 21 months (= 84 weeks) submergence (Ho *et al*., 2002). In the present study *Magnolia liliifera* wood took at least 23 months (92 weeks) to complete decay, although some did not completely decay after 29 months (116 weeks). Young wood samples decay markedly faster than the mature wood, while fewer fungi are obtained from young wood than from mature wood (Kodsueb, pers. obs.). A slower decay rate of litter means a longer period of colonization and this may lead to the higher number of fungi recovered from the present succession study. However, study on leaf decomposition suggested that the diversity of fungal species does not depend on decomposition time (Promputtha, unpublished). Factors such as composition of litter components (which is different in each plant species), size of wood, type of wood (heartwood and sapwood) and environmental factors e.g. humidity, temperature, may response to different rate of wood decomposition and the fungal diversity (Boddy and Watkinson, 1995).

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