Freshwater fungi from bamboo and wood submerged in the Liput River in the Philippines

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Eighty fungi were recorded on submerged bamboo and wood in the Liput River, Bario Alegria, Negros Occidentalis, the Philippines following collections made in April 1997 and August 2001. The frequency of occurrence of these fungi have also been investigated. The most common species overall was *Didymella aptrootii*, occurring on 23.5% of the samples, while *Astrosphaeriella papillata* (19.5%) and *Acrogenospora sphaerocephala* (14.5%) were also common. The most common species on bamboo was *Didymella aptrootii*, occurring in 39.2% of the samples, while the most common species on wood was *Savoryella aquatica* (18.7%). The average number of species identified from each sample was 2.28, which indicates a relatively high fungal diversity in the Liput River. The fungal communities on submerged bamboo and wood are compared and discussed. The results showed that, in the Liput River, bamboo support a different and diverse group of fungi in comparison to wood. The fungal community on submerged bamboo is, to some extent, similar to that on terrestrial bamboo in previous studies. The possible reasons are discussed.

Key words: biodiversity, lignicolous fungi, taxonomy

Introduction

There have been several reports of freshwater fungi on submerged wood in the tropics (e.g. Hyde and Goh, 1997, 1998; Tsui *et al*., 2000) and subtropics (Cai *et al*., 2002). Studies on the freshwater fungi in the Philippines have yielded several new taxa (e.g. *Fluminicola bipolaris* Wong and Hyde, 1999; *Boerlagiomyces grandisporus* Stanley and Hyde, 1997). There is, however, no study in the Philippines providing a checklist of fungi on submerged wood in a stream with percentage occurrence data. In this study the fungi on submerged bamboo and wood in a small stream in the Liput River, Bario Alegria, Negros

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Occidentalis, the Philippines, a tropical location, was investigated. This is the first study of freshwater fungi in a river in the Philippines and also the first study concentrating on fungi occurring on submerged bamboo. Goh and Hyde (1999) have reported the fungi on submerged wood and bamboo in the Plover Cove Reservoir in Hong Kong, but they treated bamboo and wood collectively, while Hyde *et al*. (2001, 2002), Zhou (2001) and Zhou and Hyde (2002) have reported on fungi on terrestrial bamboo.

Materials and methods

Visits were made to a small stream in the Liput River, Bario Alegria, Negros Occidentalis in the Philippines on 27 April 1997 and 18 August 2001. In the first collection, we collected 50 submerged bamboo and 50 submerged wood samples, and in the second collection we collected 70 submerged bamboo and 30 submerged wood samples. During each visit the samples were placed in snap lock plastic bags and returned to the laboratory. The samples were processed and examined following the methods described in Tsui *et al*. (2000). Fungi were isolated using single-spore isolation techniques (Choi *et al*., 1999). Materials supporting fungi were then air-dried and held in HKU(M) and YNU. Type materials of the new species were also lodged at PDD.

Samples of bamboo and wood were treated separately, with the number of collections of each fungal taxa on bamboo or wood and overall on both samples being recorded. Frequency of occurrence for each fungus was calculated based on the number of samples on which a particular fungus was found, against the total number of samples examined (Tsui *et al*., 2000). Species-area curves were also plotted to estimate the minimum number of substrates needed to collect most of the common fungi present in the habitat (Begon *et al*., 1993).

Results

A total of 200 submerged samples (120 bamboo and 80 wood) were examined for fungi, yielding 36 ascomycetes and 44 anamorphic taxa (Table 1). The most common species identified in this study was *Didymella aptrootii*, occurring on 23.5% of samples. Other common species were *Astrosphaeriella papillata* (19.5%) and *Acrogenospora sphaerocephala* (14.5%). Twenty-three species were recorded on only one occasion. The average number of fungi recorded on each sample was comparatively high, with an average of 2.28

Table 1. Checklist of freshwater fungi from the Liput River with percentage occurrence (organised in descending order of frequency on overall samples and then alphabetically by groups).

Taxa	Percentage occurrence on bamboo	Percentage occurrence on wood	Overall percentage occurrence
Didymella aptrootii K.D. Hyde	39.2	0	23.5
Astrosphaeriella papillata K.D. Hyde & J. Fröhl.	32.5	0	19.5
Acrogenospora sphaerocephala (Berk. & Broome) M.B. Ellis	20.8	5	14.5
Savoryella aquatica K.D. Hyde	3.3	18.7	9.5
Astrosphaeriella papuana Aptroot	15	0	9
Pleurophragmium bitunicatum Matsush.	14.2	1.3	9
Digitodesmium bambusicola L. Cai, K. Zhang, McKenzie, W.H. Ho & K.D. Hyde	13.3	0	8
Annulatascus liputii L. Cai & K.D. Hyde	10	0	6
Halosarpheia lotica Shearer	3.3	8.8	5.5
Roussoëlla minutella (Penz. & Sacc.) Aptroot	9.2	0	5.5
Caryospora minima Jeffers	5.8	3.8	5
Ellisembia vaginata McKenzie	8.3	0	5
Fluminicola bipolaris S.W. Wong, K.D. Hyde & E.B.G. Jones	6.7	2.5	5
Phaeoisaria clematidis (Fuckel) S. Hughes	4.2	6.3	5
Acanthophysis-like structures	7.5	0	4.5
Massarina thalassioidea K.D. Hyde & Aptroot	5.8	1.3	4
Monodictys levis (Wiltshire) S. Hughes	4.2	3.6	4
Papulospora sp. 1	3.3	5	4
Papulospora sp. 2	3.3	5	4
Helicosporium gigasporum K.M. Tsui, Goh, K.D. Hyde & Hodgkiss	5	1.3	3.5
Dictyochaeta curvispora L. Cai, McKenzie & K.D. Hyde	5	0	3
Haematonectria haematococca (Berk. & Broome) Samuels & Nirenberg.	0.8	6.3	3
Linocarpon bambusicola L. Cai & K.D. Hyde	5	0	3
Verticillium sp.	1.7	5	3
Vargamyces sp.	4.2	1.3	3
Bactrodesmium longisporum M.B. Ellis	4.2	0	2.5

Table 1. (continued).

Taxa	Percentage occurrence on bamboo	Percentage occurrence on wood	Overall percentage occurrence
Camposporium fusisporum Whitton, McKenzie & K.D. Hyde	0	6.3	2.5
Kirschsteiniothelia elasterascus Shearer	0.8	5	2.5
Pseudohalonectria longirostrum Shearer	0	6.3	2.5
Aniptodera inflatiascigera K.M. Tsui, K.D. Hyde & Hodgkiss	3.3	0	2
Astrosphaeriella stellata (Pat.) Sacc.	3.3	0	2
Candelabrum brocchiatum Tubaki	3.3	0	2
Caryospora callicarpa (Curry) Nitschke ex Fuckel	3.3	0	2
Halosarpheia heteroguttulata S.W. Wong, K.D. Hyde & E.B.G. Jones	0	5	2
Ophioceras dolichostomun (Berk. & M.A. Curtis) Sacc.	0	5	2
Tiarosporella paludosa (Sacc. & Fiori ex P. Syd.) Höhn.	0	5	2
Acrodictys liputii L. Cai, K. Zhang, McKenzie, W.H. Ho & K.D. Hyde	2.5	0	1.5
Boerlagiomyces grandisporus S.J. Stanley & K.D. Hyde	0	3.8	1.5
Camposporium quercicola Mercado, Heredia & J. Mena	2.5	0	1.5
Ellisembia adscendens (Berk.) Subram.	2.5	0	1.5
Ellisembia sp.	2.5	0	1.5
Ityorhoptrum verruculosum (M.B. Ellis) P.M. Kirk	2.5	0	1.5
Annulatascus sp.	0	2.5	1
Chloridium cylindrosporum W. Gams & Hol.-Jech.	0	2.5	1
Dactylaria longidentata Cazau, Aramb. & Cabello	0	2.5	1
Diaporthe sp.	0	2.5	1
Dictyochaeta sp.	1.7	0	1
Unidentified anamorphic fungus	1.7	0	1
Lophiostoma frondisubmersum (K.D. Hyde) Liew, Aptroot & K.D. Hyde	1.7	0	1
Massarina sp.	1.7	0	1
Nectria sp.	1.7	0	1
Ophiobolus sp.	1.7	0	1
Periconia minutissima Corda	1.7	0	1
Saccardoella horizontalis Fallah & Shearer	0	2.5	1

Table 1. (continued).

Taxa	Percentage occurrence on bamboo	Percentage occurrence on wood	Overall percentage occurrence
Spiropes caaguazuense (Speg.) M.B. Ellis	0	2.5	1
Sporidesmiella hyalosperma (Corda) P.M. Kirk	1.7	0	1
Sporidesmium paludosum M.B. Ellis	1.7	0	1
Acrodictys sacchari M.B. Ellis	0.8	0	0.5
Annulatascus velatisporus K.D. Hyde	0.8	0	0.5
Aniptodera lignicola K.D. Hyde, W.H. Ho & K.M. Tsui	0.8	0	0.5
Aquaphila albicans Goh, K.D. Hyde & W.H. Ho	0.8	0	0.5
Astrosphaeriella tornata (Berk. & M.A. Curtis) D. Hawksw. & Boise	0.8	0	0.5
Bactrodesmium stilboideum R.F. Castañeda & G.R.W. Arnold	0.8	0	0.5
Coelomycete sp.	0.8	0	0.5
Cordana abramovii E.O. Semen & Davydkina	0.8	0	0.5
Dactylaria africana (S. Hughes) G.C. Bhatt & W.B. Kendr.	0	1.3	0.5
Dictyochaeta plovercovensis Goh & K.D. Hyde	0.8	0	0.5
Dictyosporium heptasporum (Garov.) Damon	0.8	0	0.5
Gaeumannomyces sp.	0	1.3	0.5
Jahnula seychellensis K.D. Hyde	0	1.3	0.5
Lophiostoma bipolare (K.D. Hyde) Liew, Aptroot & K.D. Hyde	0	1.3	0.5
Monodictys monilicellularis Matsush.	0.8	0	0.5
Monotosporella microaquatica (Tubaki) Sv. Nilsson	0	1.3	0.5
Neta sp.	0	1.3	0.5
Phaeosphaeria sp.	0	1.3	0.5
Phomatospora berkeleyi Sacc.	0.8	0	0.5
Pseudospiropes cubensis Hol.-Jech.	0	1.3	0.5
Saccardoella minuta L. Cai & K.D. Hyde	0	1.3	0.5
Sporoschisma juvenile Boud.	0.8	0	0.5
Vanakripa gigaspora Bhat, W.B. Kendr. & Nag Raj	0	1.3	0.5

fungi per sample. The most common species on bamboo were *Didymella aptrootii* (occurring on 39.2% of the samples), *Astrosphaeriella papillata* (32.5%) and *Acrogenospora sphaerocephala* (20.8%), while the most common species on wood were *Savoryella aquatica* (18.7%), *Halosarpheia lotica* (8.8%) and *Phaeoisaria clematidis* (6.3%). The number of fungi recorded on each bamboo sample was very high, with an average of 2.88 fungi per sample, while an average of 1.40 fungi were recorded on each wood sample. New taxa identified in this study include: *Acrodictys liputii*, *Annulatascus liputii*, *Dictyochaeta curvispora, Digitodesmium bambusicola, Linocarpon bambusicola* and *Saccardoella minuta*. Several other new species require further work and collection to confirm their novel identity.

Discussion

Comparison with previous studies

This study provides further evidence that fungal diversity in tropical streams is both more diverse and differs from that of temperate streams (Goh and Hyde, 1999). Only 0.86 taxa were identified per sample in the River Coln in Britain (Hyde and Goh, 1999), whereas 2.28 taxa were identified per sample in this study. There was only one overlapping species (*Acrogenospora sphaerocephala*) between the River Coln and the Liput River in this study.

Similar studies of fungi on submerged wood in tropics have been made by Hyde and Goh (1997) in a small stream on Mt Lewis, Australia, Hyde and Goh (1998) in Riviere St Marie-Louis, Seychelles, Hyde *et al*. (1998) in the Palmiet River, South Africa, Goh and Hyde (1999) in Plover Cove Reservoir, Hong Kong and Ho *et al*. (2001) in streams from Brunei, Hong Kong and Malaysia. The four most common species, species richness (number of taxa) and the average number of fungi per sample identified in these studies are given in Table 2. A relatively high number, 2.28 taxa per sample were identified in the Liput River, while 0.9 taxa were identified per sample in the Mt Lewis stream; 1.97 taxa occurred on each sample in the Seychelles; 1.7 taxa were found per samples in the Palmiet River; 2.4 taxa were identified per sample in Plover Cove Reservoir; the number of fungi per samples in streams from Brunei, Hong Kong and Malaysia were 2.1-2.9. The diversity in the stream at Mt Lewis, Australia was distinctly lower than those in other studies. This was thought to be because the stream in Mt Lewis was seasonal and dried up in the dry season. The studies on the freshwater fungi in the Liput River yielded a relatively high fungal diversity. This may result from the fact that two different host types (submerged bamboo and wood) were studied. The number of fungi per sample

of the Liput River and Plover Cove Reservoir is similar (2.4 and 2.28) and this may be because both studies collected similar sample types.

Ho *et al*. (2001) reported the highest species richness, 79 species from 50 samples (90 species if extrapolated to 100 samples) from Tai Po Kau forest stream of Hong Kong, and that of streams in Brunei (71 species from 50 samples) and Malaysia (53 species from 50 samples) were also high. In the Liput River, we identified 80 species from 200 samples. For comparisons with studies elsewhere see Table 2. Relative low species richness were found in small streams in the Seychelles (34 taxa from 100 samples) and Mt. Lewis, Australia (42 taxa from 100 samples).

Dominant Fungi

Three species were identified on more than 10% of samples in this study. The most abundant species was *Didymella aptrootii* occurring on 23.5% samples, followed by *Astrosphaeriella papillata* (19.5%) and *Acrogenospora sphaerocephala* (14.5%). There were 23 species which occurred on only one sample, comprising 29% of the total species. With the exception of *Didymella aptrootii* occurring in both the Liput River and Plover Cove Reservoir and *Savoryella aquatica* occurring in both the Liput River and Malaysian stream, there are no overlapping species in the four most common species between this study and previous studies. [Savoryella aquatica overlapped with the Malaysian sample] *Didymella aptrootii* is a typical freshwater bambousicolous fungus (Hyde and Wong, 1999), which occurred on 39% of the bamboo samples in the Liput River and 14% of the samples in Plover Cove Reservoir. This is a very common species in tropics and has been found in several places such as Hong Kong, Malaysia and The Philippines (Hyde and Wong, 1999; Goh and Hyde, 1999; this paper).

Comparison of fungi on bamboo and wood submerged in the Liput River

In this study, 58 taxa were identified from the 120 bamboo samples (24 ascomycetes and 34 anamorphic fungi), with an average of 2.88 species per sample. There were 7 species with a percentage occurrence of more than 10%. They were *Didymella aptrootii* (39.2%), *Astrosphaeriella papillata* (32.5%), *Acrogenospora sphaerocephala* (20.8%), *Astrosphaeriella papuana* (15%), *Pleurophragmium bitunicatum* (14.2%), *Digitodesmium bambusicola* (13.3) and *Annulatascus liputii* (10%). Thirty-eight taxa were identified from 80 submerged wood samples (18 ascomycetes and 20 anamorphic fungi), with an average of 1.4 species per sample. There was, however only one species,

Table 2. Comparison of aquatic fungi on bamboo and wood submerged in streams in the Philippines, Australia, the Seychelles, South Africa, Brunei, Malaysia, Hong Kong and reservoir in Hong Kong (The data of dominant fungi from streams in Brunei, Malaysia and Hong Kong are presented as percentage abundance, the others are presented as percentage occurrence).

The Philippines, Liput River (this paper)	**Australia, Mt. Lewis, a small stream (Hyde and Goh 1997)**	**The Seychelles, small stream (Hyde and Goh 1998)**	**South Africa, Palmiet River (Hyde *et al*. 1998)**	**Hong Kong, Plover Cove Reservoir, (Goh and Hyde 1999)**	**Brunei, stream in Sangai Sitam, (Ho *et al*. 2001**	**Malaysia, a stream in Lipur Lentang, (Ho *et al*. 2001)**	**Hong Kong, Tai Po Kau forest stream, (Ho *et al*. 2001)**
Didymella aptrootii (23.5%)	*Verticillium* sp. (8%)	*Jahnula seychellensis* (30%)	*Nais aquatica* (34%)	*Kirchsteiniothelia elasterascus* (70%)	*Mamillisphaeria dimorphospora* (8.5%)	*Aniptodera lignicola* (9.5%)	*Sporoschisma uniseptatum* (3.5%)
Astrosphaeriella papillata (19.5%)	*Helicomyces roseus* (6%)	*Verticillium* sp. (26%)	*Ophioceras* sp. (22%)	*Didymella aptrootii* (14%)	*Sporoschisma uniseptatum* (7.1%)	*Savoryella lignicola* (7.6%)	*Candelabrum brocchiatum* (3.5%)
Acrogenospora sphaerocephala (14.5%)	*Jahnula bipolaris* (6%)	*Annualatascus velatisporus* (21%)	*Annulatascus velatisporus* (15%)	Unidentified coelomycetes sp. (12%)	Acanthophyses-like structures (6.4%)	*Savoryella aquatica* (5.7%)	*Massarina thalassioidea* (3.5%)
Savoryella aquatica (9.5%)	*Lophiostoma bipolare* (5%)	*Sporoschisma uniseptatum* (15%)	*Kirschsteiniothelia elasterascus* (12%)	*Halosarpheia heteroguttulata* (11%)	*Helicomyces roseus* (5.0%)	*Jahnula bipolaris* (4.8%)	*Sporoschisma nigroseptatum* (3.5%)
80 taxa (200 samples)	42 taxa (100 samples)	34 taxa (100 samples)	58 taxa (150 samples)	57 taxa (100 samples)	69 taxa (50 samples)	52 taxa (50 samples)	79 taxa (50 samples)
2.28 species per sample	0.9 species per sample	1.97 species per sample	1.7 species per sample	2.4 species per sample	2.9 species per sample	2.1 species per sample	2.9 species per sample

Table 3. Comparison of fungal communities occuring on submerged bamboo and submerged wood in Liput River.

	Bamboo (120 samples)	**Wood (80 samples)**
Fungi identified	58 (24 ascomycetes and 34 anamorphic fungi)	38 (18 ascomycetes and 20 anamorphic fungi)
Number of fungi recorded on each sample	2.88 species per sample	1.40 species per sample
Most common species	*Didymella aptrootii* 39.2% *Astrosphaeriella papillata* 32.5% *Acrogenospora sphaerocephala* 20.8%	*Savoryella aquatica* 18.7% *Halosarpheia lotica* 8.8%
Taxa occurring on bamboo or wood only	42	22
Overlapping taxa	16	

Savoryella aquatica (18.7%), with a percentage occurrence of more than 10%. Other common species were *Halosarpheia lotica* (8.8%), *Phaeoisaria clematidis* (6.3%), *Haematonectria haematococca* (6.3%), *Camposporium fusisporum* (6.3%) and *Pseudohalonectria longirostrum* (6.3%). Only 16 taxa were found on both submerged bamboo and wood. Forty-two taxa occurred on bamboo only, while 22 taxa occurred on wood only (Table 3). Six of the ten most commonly recorded species on overall samples (Table 1) were only identified from bamboo. They were *Didymella aptrootii*, *Astrosphaeriella papillata*, *Astrosphaeriella papuana*, *Digitodesmium bambusicola, Annulatascus liputii* and *Roussoëlla minutella.* These facts indicate that, in the Liput River, submerged bamboo supports a different and diverse group of fungi in comparison to wood.

Are the fungi occurring on submerged samples different from that of terrestrial samples?

There are more than 1100 species of fungi that have been described or recorded from bamboo (Hyde *et al*., 2002). Hyde *et al*. (2001) provided a checklist with percentage occurrence of saprobic fungi occurring on bamboo culms from the Philippines and Hong Kong, comprising 24 ascomycetes, 56 anamorphic taxa and 1 basidiomycete. Zhou (2001) provided a more detailed checklist of terrestrial fungi on bamboo comprising 224 ascomycetes, 76 anamorphic fungi and 3 basidiomycetes. Of the 58 taxa identified from bamboo submerged in the Liput River, 18 species overlapped with those on terrestrial bamboo in the Philippines, Hong Kong and mainland China. This result shows

that many species identified from bamboo submerged in the Liput River overlap with terrestrial bambusicolous fungi. This is interesting and may be due to several factors: Firstly, bamboo culms contain numerous vascular bundles that trap high amounts of air. It may therefore require a longer time (than wood) for bamboo to become waterlogged and truly submerged. Fryar *et al*. (2003) have shown that the fungal communities that develop on wood that has been submerged in water, do not become truly aquatic until after 6 months of submergence. To try to compensate for this, we mostly collected submerged samples trapped between rocks. Secondly, bamboo culms appear to be harder than wood and may not be that easily degraded. It may therefore require longer for freshwater fungi to colonise bamboo. If samples had been submerged in the river for a long enough period, it would then be evident whether some fungi are capable of degrading bamboo in both terrestrial and freshwater habitats. It would be interesting to investigate which are the "true" freshwater fungi that degrade submerged bamboo culms. We therefore need to place and recover bamboo baits into rivers following submergence for a long period of time.

Since the fungi on submerged bamboo are, to some extent, similar to terrestrial bambusicolous fungi, a further question arises: are freshwater fungi on submerged wood similar to the terrestrial fungi on wood? Polishook *et al*. (1996) investigated the fungi from leaf litter of two different tree species in Puerto Rico. Although several of the genera they recorded overlap with genera known from freshwater, there was, however, no specific species found to overlap with freshwater fungi. Parungao *et al*. (2002) carried out a similar study in Australia, where some genera known from freshwater, e.g. *Chaetosphaeria, Dactylaria, Dictyochaeta, Dictyosporium, Helicosporium* and *Massarina*, and several species, e.g. *Ophioceras fusiforme* and *O. tenuisporum* known from freshwater, were reported. These studies however involved leaves. We are now investigating wood in the riparian region of streams in the tropics in order to establish whether there is overlap between terrestrial and freshwater fungi. Further studies are required to establish the relationships between terrestrial and freshwater fungi and redefine definitions of freshwater fungi (Shearer, 1993).

Species-area curves

Curves were plotted to indicate the increasing number of fungi with the examination of samples (Fig 1). The number of fungi increases quickly at first, reaching asymptote at around 100 samples (bamboo) and 70 samples (wood). Therefore, the number of samples taken provides can provide a reasonable account of the total fungal diversity in the Liput River, while 30 samples indicate the most common species (above 10%).

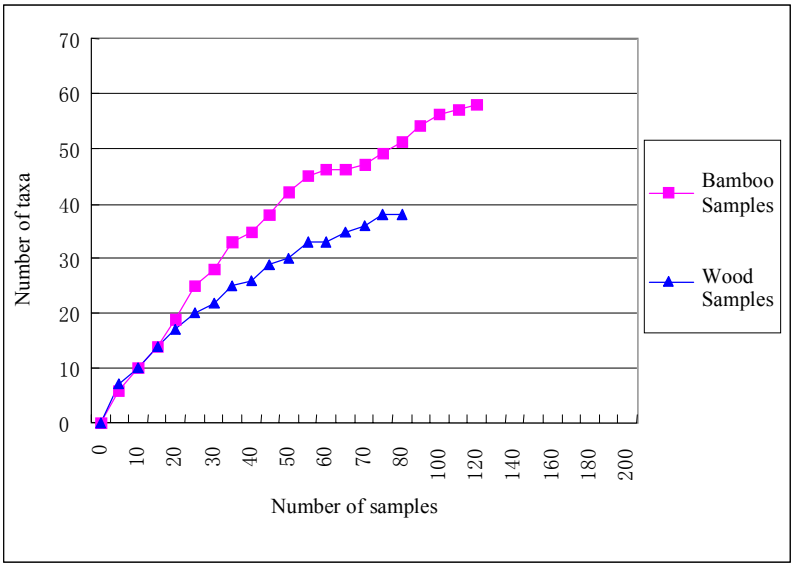

Fig. 1. Cumulative curve of number of fungi identified against number of samples examined.

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