Title	Biodiversity of fungi on submerged wood in Hong Kong streams
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Citation	Aquatic Microbial Ecology, 2000, v. 21 n. 3, p. 289-298
Issued Date	2000
URL	http://hdl.handle.net/10722/57259
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Vol. 21: 289-298, 2000 | AQUATIC MICROBIAL ECOLOGY Aquat Microb Ecol | Published June 15

Biodiversity of fungi on submerged wood in Hong Kong streams

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ABSTRACT: Woody substrates were collected in 5 freshwater streams in Hong Kong and the fungi on these substrates were investigated. A total of 153 species were identified, comprising 61 ascomycete and 92 mitosporic taxa, and 20% were previously undescribed. About 30% of the ascomycetes belonged to the genera *Annulatascus* (Annulatascaceae), *Aniptodera*, *Savoryella* (Halosphaeriaceae), *Ophioceras*, *Pseudohalonectria* (Magnaporthaceae) and *Massarina* (Lophiostomataceae). *Endophragmiella*, *Helicosporium* and *Sporoschisma* were common mitosporic genera. Species overlap occurred between different streams, and a few fungi were common in Hong Kong streams. Species composition in the Tung Chung River was distinct, and factors causing variations are discussed. Sampling techniques, the ecological role and distribution of fungi on submerged wood are discussed.

KEY WORDS: Ascomycetes · Biodiversity · Ecology · Freshwater · Hyphomycetes · Lignicolous · Stream · Wood

INTRODUCTION

Dead wood is an essential component of stream ecosystems. Fallen tree trunks, branches and twigs regulate stream dynamics by increasing the retention of organic matter, and provide habitats for a large number of organisms, including fungi, insects and even fish (Triska & Cromack 1980). Decomposition of these woody substrates is important in nutrient cycling and the rate of wood decay is determined by both physical and biological factors (Harmon et al. 1986). The role of freshwater fungi in the decomposition of organic matter is vital in detritus-based stream systems because nutrients and energy locked up within leaves and wood are released, and these can be used at higher trophic levels (Graça 1993). The conditioned leaves are more palatable to stream insects (Graça 1993).

Freshwater fungi are diverse in taxonomic groups and numbers (Goh & Hyde 1996). Aquatic hyphomycetes, known as Ingoldian fungi, on wood and leaves have been well investigated with respect to their distribution and biodiversity (Shearer & Webster 1991, Bärlocher 1992, Gönczöl & Révay 1997), and there are more than 100 species. Research on lignicolous ascomycetes and mitosporic fungi, mainly dematiaceous, has been focused on systematics (Goh et al. 1997a,b, Hyde et al. 1997, Crane et al. 1998). Biodiversity studies of these fungi have been carried out in the United States (Shearer & von Bodman 1983, Shearer & Crane 1986, Shearer 1993) and more recently in some tropical and subtropical countries (Hyde & Goh 1997, 1998a,b, Hyde et al. 1998, Goh & Hyde 1999). During a single collection of 100 woody substrates 57 species were identified (Goh & Hyde 1999), and more than 600 species have been described from woody substrates in freshwater ecosystems (M. K. M. Wong et al. 1998).

Inter-stream variations in aquatic hyphomycete communities have been observed globally (Wood-Eggenschwiler & Bärlocher 1985) and regionally (Chauvet 1991, Raviraja et al. 1998). The fungal communities also exhibited longitudinal and seasonal dynamics (Révay & Gönczöl 1990, Gönczöl & Révay 1993, 1997). For the lignicolous ascomycetes and dematiaceous hyphomycetes, little species-overlap occurred between temperate and tropical fungal communities (Shearer 1993, Hyde & Goh 1998b). Local differences in fungal communities, however, have received less attention. The

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aims of this study were to characterize the biodiversity of wood-inhabiting fungi in different freshwater habitats in Hong Kong, and to investigate if there were variations in species composition in different streams.

METHODS

Location. Hong Kong is situated on the southern coast of China. It lies between latitudes 22° 9' and 22° 37' N and longitudes 113° 52' and 114° 30' E, less than 192 km south of the Tropic of Cancer. Although located in the tropics, Hong Kong has a seasonal climate, and there is a marked seasonal temperature difference. On average, a hot wet monsoon dominates from early May to the end of September, and is replaced by a cool, dry season from November to March; the seasons are separated by 2 shorter periods of transitional weather (Dudgeon & Corlett 1994).

Study sites. Five unpolluted streams draining in separate watersheds of the New Territories and Lantau Island, Hong Kong, were selected based on accessibility and lack of human disturbance (Fig. 1). There have been few marked inter-site differences in nutrient status and chemical characteristics in many unpolluted streams (Dudgeon 1989, Dudgeon & Corlett 1994). Some water parameters of the streams are given in Table 1 (Chan 1997). The waters are soft and slightly acidic. Dissolved oxygen, and pH of the streams were approximately the same except for their concentration of nitrate and conductivity. They differed with respect to riparian vegetation and shading. Bride's Pool (BP), Hang Cho Shui (HCS), the Lam Tsuen River (LTR) and the Shing Mun Reservoir stream (SM) are surrounded by dense, tall, broad-leaved evergreen trees, and are partially shaded. The Tung Chung River (TCR), however, is largely unshaded, and the riparian vegetation consists mainly of shrubs. Most woody substrates from this stream were collected from one of its pools. The river stream bed of all habitats contains gravel and boulders.

Collection and processing of samples. Fifty woody substrates were randomly collected in BP (January 1999), HCS (September 1998), LTR (December 1996), SM (January 1998 and October 1998) and TCR (August 1997). The samples ranged from twig (ca 1 cm diameter × 30 cm length) to larger parts of logs (5 cm diameter × 30 cm length). All the samples were placed in plastic bags in the field, and returned to the laboratory. They were incubated in plastic boxes (50 × 10 × 10 cm) lined with moistened tissue paper at 26°C for 6 wk. The woody substrates were examined on Day 7 and then over next 30 d under a dissecting microscope for fruiting bodies, and any fungi present were recorded, identified and isolated following the method described in Hyde & Goh (1999).

Data analysis. Numbers of species, frequencies of occurrence of each species and abundance (total occurrence of all fungi) were recorded and calculated for each sampling site. The species diversity of each sampling site was calculated using Shannon-Wiener's index (H) (Begon et al. 1993):

$$H = -\Sigma(N_i/N)\log^2(N_i/N)$$

where N = the number of individuals, and N_i = the number of individuals in the ith species. Frequency of occurrence was calculated based on the following formula:

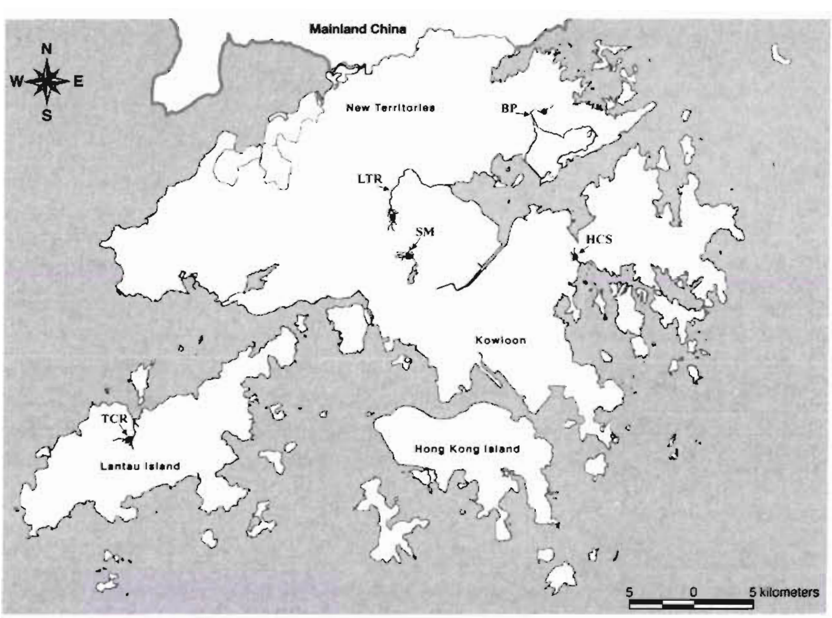

Fig. 1. A map of Hong Kong showing the freshwater sites investigated in this study. BP: Bride's Pool; HCS: Hang Cho Shui; LTR: the Lam Tsuen River; SM: a stream in Shin Mun Reservoir; TCR: the Tung Chung River

Table 1. Water parameters of all streams (Chan 1997) (BP: Bride's Pool; HCS: Hang Cho Shui; LTR: the Lam Tsuen River; SM: a stream in Shing Mun Reservoir; TCR: the Tung Chung River)

	BP 22°30'N 114°14'E	HCS 22°24'N, 114°16'E (data obtained from a stream nearby)	LTR 22°27'N 114°08'E	SM 22°24'N 114°09'E	TCR 22°16'N 113°56'E
Dissolved oxygen (mg l^{-1})	8.1	7.7	7.8	8	9.5
Conductivity (µS cm^{-1})	39.2	71.9	91.1	44.4	75.4
pH	6.6	5.98	6.09	6.77	6.4
Nitrates (mg l^{-1})	4.0	3	7.0	4	1
Phosphates (mg l^{-1})	0	0.02	0	0	0
Total suspended solid (mg l^{-1})	1	2.8	4	0.8	1.8

$$\frac{\text{No. of samples of wood that a particular species occurred on}}{\text{No. of samples of wood examined}} \times 100$$

Dominance-diversity curves were plotted as a reflection of the relative abundance of species in each sampling habitat (Kent & Coker 1992). To compare the similarity of the species composition between different habitats, Sørensen's index of similarity (S) was applied (Magurran 1988). The index was calculated with the formula: $S = 2c/a+b$ where a = total number of species at site 1, b = total number of species at site 2, and c = number of species common to both sites. Similarity is expressed with values between 0 (no similarity) and 1 (absolute similarity).

RESULTS

Mycological diversity

A total of 153 fungal taxa were collected (Table 2), consisting of 61 ascomycete (representing 40% of all mycota) and 92 mitosporic fungi (60%). About 20% of the fungi were previously undescribed. Most ascomycete species belonged to the families Annulatascaceae, Halosphaeriaceae, Lasiosphaeriaceae, Lophiostomataceae and Magnaporthaceae (Barr 1990, Hawksworth et al. 1995, S. W. Wong et al. 1998, sensu Shearer et al. 1999) (Fig. 2). Several genera were well represented in aquatic environments and included *Aquaticola*, *Annulatascus*, *Aniptodera*, *Halosarpheia*, *Massarina*, and *Savoryella* (Table 2). Fifty-six mitosporic fungal genera were identified in this study, and *Dactylaria* and *Helicosporium* were the most common ones, with 5 species in each genus. Other common genera included *Helicomyces*, *Chloridium*, *Monodictys* and *Sporoschisma*, each of which had 4 species (Table 2).

The following species occurred frequently in more than 1 stream: *Aniptodera chesapeakensis*, *Aquaticola rhomboidea*, *Candelabrum brocchiatum*, *Helicomyces torquatus*, *Helicosporium* sp., *Massarina ingoldiana*, *Massarina thalassioidea*, *Savoryella lignicola*, *Sporoschisma nigroseptatum*, *Sporochisma uniseptatum* (Table 3). Some species (Table 2), although low in frequency of occurrence, were also recorded in all streams, e.g. *Annulatascus velatisporus*, *Massarina bipolaris*, *Ophioceras dolichostomum*, *Torrentispora fibrosa*, *Acrogenospora sphaerocephala*, *Ellisembia opaca*, *Exserticlava vasiformis*, *Sporidesmiella hyalospermum* var. *hyalospermum, and Sporoschisma saccardoi.* Some species were, however, more abundant in a particular stream, such as *Phaeoisaria clematidis* in HCS, *Stanjehughesia nigroaca* and *Monotosporella setosa* var. *macrocarpa* in the TCR, and *Massarina purpurascens* in the LTR.

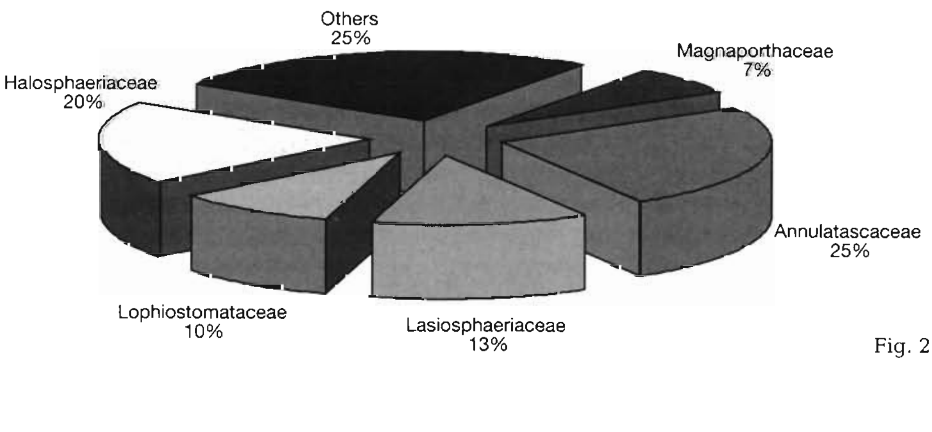

Fig. 2. Ascomycete families encountered

Table 2. Frequency of occurrence of fungi on submerged wood in streams in Hong Kong

Species name	BP	HCS	LTR	SM1	SM2	TCR
Ascomycetes						
Annulatascaceae						
Annulatascus biatriisporus K. D. Hyde	–	–	–	–	2%	–
Annulatascus sp.	–	–	2%	–	–	–
Annulatascus velatisporus K. D. Hyde	6%	–	–	4%	8%	2%
Aquaticola hyalomura W. H. Ho, K. M. Tsui, K. D. Hyde & Hodgkiss	2%	2%	6%	6%	–	–
Aquaticola sp.	–	2%	–	–	2%	2%
Aquaticola sp.	–	–	–	–	2%	–
Aquaticola rhomboidea W. H. Ho, K. M. Tsui, K. D. Hyde & Hodgkiss	4%	10%	18%	12%	8%	–
Ascotaiwania hsilio H. S. Chang & S.-Y. Hsieh	–	2%	–	–	–	–
Cateractispora viscosa S. W. Wong	–	2%	–	–	–	–
Clohiesia corticola K. D. Hyde	–	2%	–	–	–	–
Clohiesia lignicola K. M. Tsui, K. D. Hyde & Hodgkiss	–	–	–	2%	–	6%
Pseudoproboscispora aquatica S. W. Wong & K. D. Hyde	2%	–	6%	4%	–	–
Rivulicola incrustata K. D. Hyde	4%	–	–	–	–	–
Torrentispora fibrosa K. D. Hyde	–	–	2%	4%	2%	2%
Halosphaeriaceae						
Aniptodera chesapeakensis Shearer	6%	2%	16%	30%	18%	4%
Aniptodera inflatiascigera K. M. Tsui, K. D. Hyde & Hodgkiss	–	–	2%	–	–	–
Aniptodera lignatilis K. D. Hyde	–	–	2%	–	–	–
Aniptodera sp.	–	–	–	–	–	2%
Halosarpheia aquadulcis Hsieh, H. S. Chang & E. B. G. Jones	2%	–	–	–	–	–
Halosarpheia heteroguttulatta S. W. Wong & K. D. Hyde	–	–	2%	2%	–	–
Halosarpheia lotica Shearer	–	–	4%	–	–	–
Lutrellia estuarina Shearer	–	–	–	–	–	4%
Nais aquatica K. D. Hyde	–	–	4%	–	–	–
Savoryella aquatica K. D. Hyde	–	–	–	4%	–	–
Savoryella lignicola E. B. G. Jones & R. A. Eaton	26%	–	–	10%	4%	–
Savoryella verrucosa Minoura & Muroi	–	–	–	2%	–	–
Clypeosphariaceae						
Jobellisia sp.	–	–	–	–	–	2%
Lasiosphaeriaceae						
Cercophora costariensis (Carroll & Munk) O. Hilber & R. Hilber	–	–	–	4%	–	–
Cercophora caudata (Curr.) Lundq.	–	–	8%	–	–	–
Chaetosphaeria hiugensis Hino	–	–	–	2%	–	–
Lasiosphaeria sp.	–	–	–	–	2%	–
Lasiosphaeria immersa P. Karst	–	–	2%	–	–	–
Lasiosphaeria lapaziana Carroll & Munk	–	4%	–	–	–	–
Melanochaeta hemipsila (Berk & Broome) E. Mull., Harr. & Sulmont	–	–	–	4%	–	–
Melanochaeta sp.	–	–	–	–	–	2%
Lophiostomataceae						
Massarina corticola (Fuckel) L. Holm	2%	–	–	–	–	–
Massarina bipolaris K. D. Hyde	–	6%	2%	2%	6%	6%
Massarina ingoldiana Shearer & K. D. Hyde	8%	–	8%	10%	12%	–
Massarina purpurascens K. D. Hyde & Aptroot	2%	–	14%	2%	–	–
Massarina thalassioidea K. D. Hyde & Aptroot	10%	6%	16%	6%	12%	–
Vaginatispora aquatica K. D. Hyde	4%	–	–	–	–	–
Hypocreaceae						
Nectria haematoccoca Berk. & Br.	–	2%	6%	2%	–	–
Magnaporthaceae						
Ophioceras commune Shearer	–	4%	16%	–	–	–
Ophioceras dolichostomum (Berk. & Curk.) Sacc.	4%	–	8%	4%	6%	–
Pseudohalonectria adversaria Shearer	–	–	–	4%	–	–
Pseudohalonectria lignicola Minoura & Muroi	–	–	–	2%	–	–
Massariaceae						
Caryospora minima Jeffers	2%	–	–	–	–	–

Table 2. (continued)

Species name	BP	HCS	LTR	SM1	SM2	TCR
Orbiliaceae						
Orbilia luterobella (Nyl.) P. Karst.	–	–	2%	2%	–	–
Phyllachoraceae						
Glomerella sp.	2%	–	–	–	–	2%
Platystomaceae						
Astrosphaeriella trochus (Penz. & Sacc) D. Hawksw.	–	–	–	2%	–	–
Pleomassariaceae						
Kirschsteiniothelia elasterascus Shearer	–	–	2%	–	–	–
Valsaceae						
Diaporthe sp.	–	6%	–	–	–	–
Incertae sedis						
Jahnula bipolaris (K. D. Hyde) K. D. Hyde	–	–	–	4%	8%	–
Phomatospora berkeleyi Sacc.	2%	–	–	–	4%	–
Saccardoella aquatica K. M. Tsui, K. D. Hyde, Hodgkiss & Goh	–	–	2%	–	–	–
Ascomycete sp. 1	–	–	2%	–	–	–
Ascomycete sp. 2	–	–	–	–	–	2%
Ascomycete sp. 3	–	2%	–	–	–	–
Ascomycete sp. 4	–	–	–	–	–	2%
Ascomycete sp. 5	4%	–	–	–	–	–
Ascomycete sp. 6	–	–	–	4%	–	–
Coelomycetes						
Coelomycetes sp. 1	6%	–	2%	–	–	–
Coelomycetes sp. 2	–	2%	2%	–	–	–
Coelomycetes sp. 3	–	–	6%	–	–	–
Satchmopsis sp.	–	–	4%	–	–	–
Trematophora sp.	–	–	2%	–	–	–
Hyphomycetes						
Acrogenospora sphaerocephala (Berk. & Broome) M. B. Ellis	–	2%	–	2%	4%	4%
Aegerita sp.	–	–	2%	–	–	–
Anguillospora gigantea Ranzoni	–	–	6%	–	–	–
Arachnophora hughesii R. F. Castaneda & Guarro	–	–	6%	–	–	–
Bahusutrabeeja dwaya Subram. & Bhatt	–	–	2%	–	–	–
Berkleasmium concinnum (Berk.) Moore	–	–	–	–	–	4%
Berkleasmium corticola (Karst.) Moore	–	2%	–	–	–	–
Brachiosphaera tropicalis Nawawi	–	–	4%	–	–	–
Cacumisporium sp.	–	–	–	–	–	4%
Camposporium antennatum Harkn.	–	–	12%	2%	–	–
Canalisporium caribense (Hol.-Jech. & Mercado) Nawawi & Kuthub.	–	2%	2%	–	2%	–
Canalisporium pulchrum (Hol.-Jech. & Mercado) Nawawi & Kuthub.	–	–	2%	–	2%	–
Cancellidium applanatum Tubaki	–	–	–	4%	2%	–
Candelabrum brocchiatum Tubaki	16%	8%	8%	24%	12%	–
Candelabrum sp.	–	–	–	10%	–	–
Chaetochalara sp.	2%	2%	–	–	2%	–
Chloridium botryoideum (Corda) Hughes var. *minutum* (Sacc) W. Gams & Hol.-Jech.	–	–	–	–	–	6%
Chloridium matsushmae W. Gams & Hol.-Jech.	–	2%	–	–	–	–
Chloridium sp.	–	–	–	2%	–	–
Cladorrhinum foecundissimium Sacc. & Marchal	–	–	2%	4%	–	–
Codineae britannica Ellis	2%	–	–	–	–	–
Cordana musae (Zimm.) Höhnel	–	–	–	–	–	2%
Dactylaria sp.	–	–	–	–	–	2%
Dactylaria hoogi R. F. Castaneda & W. B. Kendr.	–	–	6%	–	–	–
Dactylaria hyalotunicata K. M. Tsui, Goh & K. D. Hyde	2%	–	2%	6%	–	4%
Dactylaria malaysianum Matsushi.	–	–	–	–	–	4%
Dactylaria triseptata (Matsush.) R. F. Castaneda & W. B. Kendr.	2%	–	2%	–	–	2%

Table 2. (continued)

Species name	BP	HCS	LTR	SM1	SM2	TCR
Dictyochaeta coffeae (Maggi & Persiani) Kuthubu. & Nawawi	2%	–	12%	–	–	–
Dictyochaeta subfuscospora Kuthub. & Nawawi	–	–	–	–	–	2%
Dictyosporium digitatum J. L. Chen, C. H. Hwang & S. S. Tzean	–	–	–	2%	–	–
Elegantimyces sporidesmiopsis Goh, K. M. Tsui & K. D. Hyde	–	–	2%	–	–	–
Ellisembia leonense McKenzie	–	–	4%	–	–	–
Ellisembia opaca (Cooke & Harkn.) Subram.	2%	8%	4%	6%	–	2%
Endophragmiella sp. 1	–	–	2%	–	–	–
Endophragmiella sp. 2	–	–	–	2%	–	–
Exserticlava vasiformis (Matsush) S. Hughes	–	–	–	8%	–	–
Gonytrichum chlamydosporium var. *chlamydospoium*	–	2%	2%	2%	–	2%
Haplochalara angulospora Linder	–	6%	–	–	–	–
Helicomyces roseus Link	–	8%	6%	2%	4%	–
Helicomyces torquatus Lane & Shearer	14%	–	–	–	10%	–
Helicosporium aquaticus sp. nov.	2%	–	–	–	4%	–
Helicosporium griseum Berkeley & Curtis	18%	12%	14%	18%	–	–
Helicosporium guianenses Linder	–	2%	–	2%	–	–
Helicosporium pallidum Cesati	10%	–	16%	4%	2%	4%
Helicosporium sp.	2%	–	–	–	–	–
Isthmolongispora intermedia Matsush.	–	–	–	–	–	4%
Janetia cuviapicis Goh & K. D. Hyde	–	2%	–	–	–	6%
Melanocephala cupulifera S. Hughes	–	4%	–	–	–	–
Menisporopsis multisetulata K. M. Tsui, Goh & K. D. Hyde	–	–	4%	–	–	–
Monodictys sessilis Hol.-Jech.	–	2%	–	–	–	–
Monodictys putredinis (Wallr.) S. Hughes	–	2%	2%	–	–	–
Monodictys striata (Petch) V. Rao & de Hoog	–	2%	–	–	–	–
Monodictys sp.	–	8%	2%	–	4%	–
Monotosporella setosa var. *macrocarpa* S. Hughes	2%	–	–	–	–	10%
Monotosporella sp.	–	6%	–	–	–	–
Neta lignicola Shearer	–	–	–	2%	–	–
Phaeoisaria clematidis (Fuckel) S. Hughes	4%	12%	10%	8%	–	–
Phialogeniculata guadelcanalensis Matsush.	–	–	–	2%	–	2%
Pleurothecium recurvatum (Morgan) Höhnel	2%	2%	–	2%	2%	–
Pseudobotrytis terrestis (Timonin) Subram.	–	4%	–	–	–	–
Rhinocladiella sp.	2%	2%	6%	–	–	–
Sarcopodium circinatum Ehrenb ex Schlecht	–	–	2%	–	–	–
Spadicoides atra (Corda) Hughes	–	–	–	–	–	2%
Spadicoides abovatum (Cooke & Ellis) S. Hughes	–	–	–	–	–	2%
Spirosphaera floriformis Beverwijk	–	–	–	8%	4%	4%
Sporidesmiella hyalosperum (Corda) P. M. Kirk var. *hyalosperum*	2%	2%	4%	2%	–	–
Sporidesmiella incrassata Kuthub. & Nawawi	–	–	–	–	–	2%
Sporidesmium macrurum M. B. Ellis	–	–	–	–	–	2%
Sporidesmium dissolvens Hol.-Jech., Mercado & Mena	–	–	2%	–	–	–
Sporidesmium sp.	–	–	–	–	–	2%
Sporoschisma juvenile Boud.	–	–	2%	–	–	–
Sporoschisma nigroseptatum D. Rao & R. Rao	2%	2%	10%	12%	16%	12%
Sporoschisma saccardoi E. W. Mason & S. Hughes	–	2%	4%	8%	4%	–
Sporoschisma uniseptatum Bhat & W. B. Kendr.	12%	10%	24%	8%	8%	–
Stanjehughesia nigroaca (B. C. Sutton) Subram.	–	–	–	–	–	10%
Thozetella effusa B. Sutton & G. T. Cole	2%	–	–	–	–	–
Thozetella nivea (Berk. & F. Mull.) O. Kuntze	–	–	–	–	–	2%
Tricladium attenuatum Iqbal	2%	–	6%	2%	–	–
Triposporium elegans Corda	–	–	–	–	2%	–
Vanakripa sp.	2%	2%	–	–	–	–
Verticillium sp.	–	–	4%	–	2%	6%
Virgariella atra S. Hughes	–	2%	–	–	–	–
Xylomyces elegans Goh, W. H. Ho, K. D. Hyde & K. M. Tsui	2%	–	–	–	4%	–
Yinmingella mitriformis Goh, K. M. Tsui & K. D. Hyde	–	–	–	–	–	2%
Zanclospora brevispora S. Hughes & W. B. Kendr. var. *brevispora*	–	–	–	–	–	2%
Hyphomycetes sp. 1	–	–	–	–	4%	–
Hyphomycetes sp. 2	–	–	–	–	2%	–

Species richness and abundance

The highest species diversity was recorded in the LTR in terms of taxa and abundance, followed by the SM (in January 1998). Diversity for the SM, however, dropped remarkably after 9 mo (October 1998). The number of taxa collected in BP, HCS and the TCR was similar. In general, species diversity (Shannon) was high, with values more than 5 for all streams, except BP and SM (October 1998) (Table 4). Dominance-diversity curves (Figs. 3 and 4) indicate that a high proportion of species occurred once or twice.

The similarity values among all sampling sites are presented in Table 5. The highest similarity in species composition (0.467) was found between the LTR and the SM (January 1998), and this was even higher than the similarity of the same habitat (0.444) sampled in 2 different months in the SM (January and October 1998). The TCR, situated on Lantau Island, had low values of similarity when compared with other habitats, implying its fungal community was distinct.

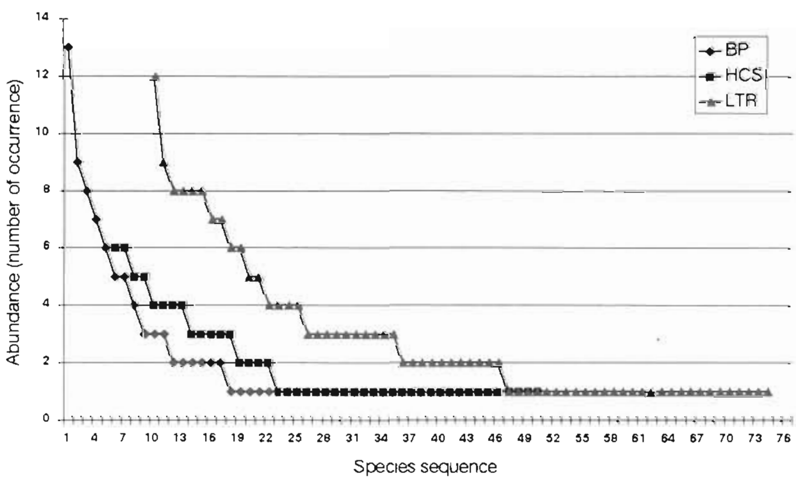

Fig. 3. Dominance-diversity curve for BP, HCS and LTR

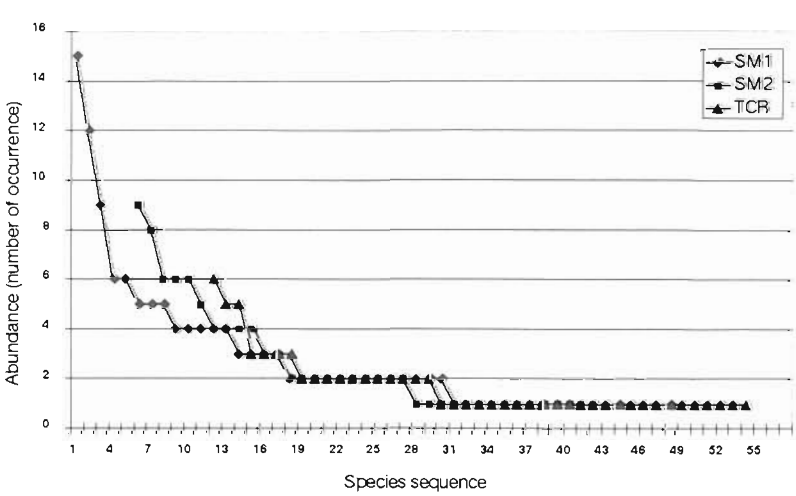

Fig. 4. Dominance-diversity curve for SM1, SM2 and TCR

DISCUSSION

Local variations

A comparison of the fungal communities at the different streams examined illustrates dissimilarities in species composition. The fungal community at the TCR was particularly distinctive. According to the river continuum concept (RCC), the stream morphology, hydrology, and allochthonous and autochthonous inputs interact to influence the aquatic plankton and invertebrate community (Vannote et al. 1980). Differences in the extent of shading by riparian vegetation affects the amount of detritus in the streams, thus affecting macroinvertebrate community structure (Dudgeon 1989, Dudgeon & Corlett 1994). BP, HCS, the LTR and SM are largely shaded sites, where the canopies of riparian trees interlock over the streams. These sites have a highly allochthonous food base. On the other hand TCR is surrounded by shrubs and is largely unshaded (Dudgeon & Corlett 1994). The influence of autochthonous input on the energy base in the TCR may affect the distinct taxonomic composition. The distinct fungal community at the TCR may also be influenced by the fact that woody substrates were mostly collected in a pool (static water) where there was a lower concentration of dissolved oxygen (Ho 1998), in comparison to other lotic (running water) habitats.

In this study, some lignicolous fungal species appeared to be associated with specific woody substrates (having specific color and texture), even though the host species cannot be identified (C.K.M.T. pers. obs.). Perhaps these fungi occurred at different stages during the wood decay process (Ho 1998), but substrate specificity cannot be ruled out. It is well established that changes in aquatic hyphomycete communities are correlated with changes in the riparian vegetation (Thomas et al. 1989, Fabre 1996). Different substrates in streams may selectively inhibit or stimulate colonization of some fungal species (Bärlocher 1992) and cause variations in community structure (Thomas et al. 1992). Although 2 studies have shown that the lignicolous fungi have little substratum specificity (Révay & Gönczöl 1990, Ho 1998), few freshwater ascomycetes occur on both woody and herbaceous substrates (Shearer 1999), which may be an indication of showing substratum specificity.

However, the results were cautiously interpreted further because there appears to be minor differences in water parameters of the streams. Collections at different times provide very different results. There is a marked change in fungal communities in the SM in January and October 1998. The quality (length and diameter) of woody substrates was also not considered. The number of basidiomycetes on decaying wood in the terrestrial environment was correlated with the diameter and length of logs (Hoiland & Bendiksen 1997).

Table 3. Eight most frequently occurring species in each of 6 Hong Kong streams

	BP	HCS	LTR	SM1	SM2	TCR
Candelabrum brocchiatum	×	×	×	×	×	
Helicomyces torquatus	×		×		×	
Helicosporium griseum	×	×		×		
Helicosporium pallidum	×					×
Massarina ingoldiana	×			×	×	
Massarina purpurascens	×		×			
Savoryella lignicola	×			×		
Sporoschisma uniseptatum	×	×	×			
Massarina thalassioidea		×	×		×	
Monodictys nigrocephala		×				
Phaeiosaria clemiatids		×				
Aquaticola rhomboidea		×	×	×	×	
Helicomyces roseus		×				
Aniptodera chesapeakensis			×	×	×	
Annulatascus velatisporus					×	
Ophioceras commune			×			
Candelabrum sp.				×		
Sporoschisma nigroseptatum				×	×	×
Clohiesia lignicola						×
Janetia curviapicis						×
Monotosporella setosa var. *macrocarpa*						×
Chloridium botryoideum var. *minutum*						×
Stanjehughesia nigroaca						×
Verticillium sp.						×

Ecology and distribution

There are great differences in species composition between Hong Kong and elsewhere, e.g. Australia, Britain, Brunei, Malaysia and South Africa (Hyde & Goh 1997, 1998a,b, 1999, Ho 1998, Hyde et al. 1998). With the exception of *Annulatascus velatisporus*, *Massarina bipolaris*, *Savoryella lignicola* and *Sporoschisma uniseptatum*, most common fungi in the freshwater sites were different. Even though there is no comprehensive review dealing with the biogeography of wood-inhabiting fungi in freshwater habitats, temperature and geographical factors are regarded as crucial in determining global distribution patterns (Wood-Eggenschwiler & Bärlocher 1985). Only 1 species recorded in the River Coln, UK, has also been found in other tropical or subtropical collections (Hyde & Goh 1999). Yuen et al. (1999) found that tropical freshwater fungi had faster growth rates than temperate species, although both had similar optimum temperatures for growth. The temperate fungi may be out-competed by tropical fungi in tropical regions. Also, temperature requirements and the capabilities of fungi for producing enzymes varied depending on where they had been isolated from. Fungi may, therefore, have geographical races (Yuen et al. 1999), and this may account for the absence of species in certain regions.

The common ascomycete genera in Hong Kong were *Annulatascus*, *Aniptodera*, *Halosarpheia*, *Massarina* and *Ophioceras*. This was consistent with observations from Hyde et al. (1997) that they are common tropical genera. Of the 288 ascomycetes listed by Shearer (1993), only 8 were found in this study, which was an illustration of the difference in fungal communities in tropical and temperate regions.

The common ascomycetes and mitosporic fungi in this study have also been found in the Tai Po Kau stream and Plover Cove Reservoir, Hong Kong (Ho 1998, Goh & Hyde 1999). It would appear that fungal communities in Hong Kong comprise a 'core group' of a few species, such as *Aniptodera chesapeakensis*, *Annulatascus velatisporus*, *Aquaticola rhomboidea*,

Table 4. Species diversity in various streams. *R*: Ratio of hyphomycetes to ascomycetes

	BP	HCS	LTR	SM1	SM2	TCR
Hyphomycetes	25	30	36	27	21	29
Ascomycetes	16	14	24	26	16	13
Coelomycetes	1	1	5	0	0	0
R	1.47	2.14	1.58	1.04	1.31	2.23
Number of species	42	45	65	53	37	42
Abundance	103	88	181	144	96	75
Number of species per sample	2.1	1.8	3.8	2.9	1.9	1.5
Shannon diversity index	4.8	5.11	5.53	5.22	4.79	5.13

Candelabrum brocchiatum, *Helicomyces torquatus*, *Helicomyces roseus*, *Helicosporium* sp., *Massarina ingoldiana*, *Massarina thalassioidea*, *Ophioceras dolichostomum*, *Sporoschisma nigroseptatum*, and *Sporochisma uniseptatum*. M. K. M. Wong et al. (1998) suggested that 'keystone species' occurred in freshwater ecosystems. Since no ascomycetes and mitosporic fungi are likely to be able to produce all of the lignocellulose-degrading enzymes to degrade wood, they may work as a consortium in wood degradation in the freshwater environment, and therefore are vital to the maintenance of the ecosystem (M. K. M. Wong et al. 1998). If a fungus cannot produce lignocellulose-degrading enzymes, it is unlikely to contribute to wood decay or be part of a consortium. In fact there are many microfungi that occur in wood in the terrestrial environment that rely on readily assimilable nutrients and do not decay the wood (Rayner & Boddy 1988). Further physiological, anatomical and ecological studies are therefore necessary in order to verify if the core group has the ability to form soft rot cavities and to decay wood, and are keystone species in the freshwater ecosystem.

As far as the minimum sampling effort (number of woody substrates) is concerned, 50 could be an optimum number. In this study, the number of taxa identified from single collections at 5 streams in Hong Kong ranged from 37 to 67. Ho (1998) also collected 71, 79 and 53 fungal taxa from Brunei, Hong Kong (the Tai Po Kau stream) and Malaysia respectively after examining 50 woody substrates. The studies carried out by Hyde and co-workers were based on collections of 100 or more woody substrates. Thirty-nine and 42 taxa were identified from Lake Barrine and Mount Lewis, Australia (Hyde & Goh 1997, 1998a), and 58 were recorded from the Palmiet River, South Africa (Hyde et al. 1998). Twenty-eight and 34 taxa were recorded from the River Coln, Britain, and from the Seychelles respectively (Hyde & Goh 1998b, 1999). The differences in species diversity may be related to temperature and geography as discussed above, but questions on the period of incubation and the importance of extensive and in-depth investigation are also raised. Prolonged incubation generally increases the diversity of fungi (Hyde & Goh 1998a). A greater fungal diversity is also found if samples are collected periodically over a longer time period because of the seasonal occurrence of certain taxa. More than 100 fungal taxa were identified from the USA (Shearer & Crane 1986), from the Tai Po Kau stream, Hong Kong (Ho 1998) and from the LTR Hong Kong (Tsui 1999), which illustrates the need for long-term studies.

Table 5. Index of similarity among different streams

	BP	HCS	LTR	SM1	SM2	TCR
BP		0.341	0.4	0.438	0.35	0.188
HCS			0.286	0.347	0.341	0.161
LTR				0.467	0.327	0.165
SM1					0.444	0.253
SM2						0.253
TCR						

With the exception for BP and the SM (October 1998), high values of species richness (Shannon-Wiener's index), usually of more than 5, were recorded. This is because a large number of species only occurred once or twice. The application of species diversity measures to this study is therefore questionable because the value of indices should not exceed 5 in natural communities (Krebs 1999). Although the number of species may be a better indicator, further studies are required to resolve how well the presence of fruiting bodies on wood reflects the distribution of mycelium inside the wood.

CONCLUSION

A total of 153 fungal taxa were found in different freshwater streams in Hong Kong, and about 30 species were previously undescribed. These high numbers illustrate the high diversity of fungi in subtropical regions. The fungal community in the TCR was distinct, and there were also variations in species composition between other streams. Differences in riparian vegetation composition, and substrate specificity of fungi are suggested to be important factors in regulating fungal communities. Further research is necessary in order to verify the presence of keystone species, and many species await discovery.

Acknowledgements. We are grateful to Dr T. K. Goh for the identification of mitosporic fungi. We thank 3 anonymous reviewers for constructive comments on an earlier version of this manuscript. Ken Wong, Michelle Wong and Helen Leung are thanked for technical assistance. C.K.M.T. would like to thank The University of Hong Kong for the award of a Postgraduate Studentship.

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Editorial responsibility: John Dolan, Edgewater, Maryland, USA

Submitted: November 2, 1999; Accepted: February 22, 2000
Proofs received from author(s): April 17, 2000