Freshwater fungi in Lake Dianchi, a heavily polluted lake in Yunnan, China

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Freshwater fungi on submerged woody substrates and grasses were investigated in Lake Dianchi, a highly polluted lake in Kunming, Yunnan Province, China. One hundred submerged woody substrates were collected from this lake every three months and examined for fungi to investigate seasonal variation. A total of 97 fungi were recorded, including 56 ascomycetes and 41 anamorphic fungi. The occurrence of these fungi was recorded and the Shannon-Weiner index (H´) was used to evaluate the fungal diversity. The results showed that the variation among the four seasonal collections were insignificant. The diversity indices (H´) at the four season collections varied from 3.155 to 3.681. The fungal community on woody substrates from Lake Dianchi is compared with that from Lake Fuxian during the same season and differences were apparent (similarity index = 0.337). The diversity was higher in Lake Fuxian (H´ = 3.808) than in Lake Dianchi (H´ = 3.368) and this may be related to riparian vegetation and pollution. The effects of pollution on freshwater fungal communities are discussed. One hundred submerged samples each of three monocotyledon species (*Phragmites australis*, *Pennisetum purpurreum* and a bamboo species) were collected from Lake Dianchi and examined for fungi. The communities on each grass species are compared and discussed in relation to host-specificity.

Key words: anamorphic fungi, ascomycetes, fungal community, fungal diversity, host specificity, pollution.

Introduction

Freshwater fungi have the ability to decompose organic materials and play an important role in nutrient cycling in freshwater ecosystems (Chamier, 1985; Wong *et al*., 1998; Abdel-Raheem and Shearer, 2002). Several studies on the diversity of freshwater fungi on submerged wood have been carried out in temperate (Shearer, 1993; Kane *et al*., 2002), tropical (Sivichai *et al*., 2002) and subtropical regions (Hyde *et al*., 1998). Different ecological habitats have

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also been investigated, including streams (Hyde and Goh, 1997), rivers (Cai *et al*., 2003b), ponds (Fisher and Spooner, 1987), reservoirs (Goh and Hyde, 1999), tree holes (Gönczöl and Révay, 2003), water-cooling towers (Udaiyan, 1989) and lakes (Hyde and Goh, 1998; Cai *et al*., 2002). Several studies reported the effect of pollutants on freshwater fungal communities (e.g. Tan and Lim, 1984; Maltby and Booth, 1991; Au *et al*., 1992a,b; Bärlocher, 1992; Tsui *et al*., 2001a) and Krauss *et al*. (2003) reviewed the effect of various types of compounds on diversity and ecological functions of aquatic hyphomycetes. The effects of pollutants on fungi inhabiting woody substrates in lake are still not clear.

This study was carried out in a severely polluted lake, Lake Dianchi, in order to (1) establish the diversity and community of freshwater fungi on woody substrates in the lake; (2) provide data on the geographic distribution of freshwater fungi by comparing the fungal communities in Lake Dianchi with that in other freshwater bodies; (3) establish the seasonal influence on fungal communities; (4) record the diversity of saprobic fungi on three monocotyledonous hosts and explore the relationship between host and fungal communities.

Materials and methods

Study sites

Dianchi Lake (24º40′~25º03′N，102º37′~102º48′E), the largest plateau lake in Yunnan Province, lies at the foot of Western Mountain, southwest of Kunming. The lake covering an area of 370 km^2, 150 km long and 40 km wide is the sixth largest freshwater lake in China. Over the past 2 decades, illegal industrial and domestic waste input and heavy use of chemical fertilizers and pesticides from areas surrounding the lake has resulted in the lake becoming severely polluted. Increased human activity also led to land abuse, erosion processes, forest destruction, land reclamation at shores, over fishing and the introduction of exotic edible fish species. As a result, the lake ecosystem has changed into a turbid water body and many species, including water plants and fish species have disappeared (Li, 1989; Zhao *et al*., 1999).

The water of Lake Dianchi is dark yellow-green with a low transparency (SD) of 0.60 m (Jin, 2003a). Serious eutrophication with extremely high concentrations of TN (1-16 mg/L), TP (0.08-1.7 mg/L), Chl-*a* (20-140 mg/m^3) and TSI_G (56.43) accompanied by serious organic pollution with very high concentrations of COD_{Mn} (8.40mg/L) and BOD_5, exceeding the Grade V water has occurred (Jin, 2003a,b; The State Environmental Protection Administration of China, 2003). In all, the average nutrient indices of total lake has reached 72.8 with the water mainly in the hypertrophic level (The State Environmental Protection Administration of China, 2003). The major chemical and physical parameters of the water at our sampling times are listed in Table 1 (Water assayed by the Department of Ecology, Yunnan University).

Sample collection

The natural vegetation around this lake is dominated by Burma pine, China armand pine, willow and some broad leaved ever green plants. Submerged woody substrates were collected haphazardly from Lake Dianchi at four periods during 2002-2003 representing spring (2 April 2002), summer (7 July 2002), autumn (18 October 2002) and winter (29 January 2003). One hundred samples were collected each time. One hundred samples each of submerged bamboo, *Pennisetum purpurreum* and *Phragmites australis* were additionally collected in the winter of 2003 on 29 January. Careful examination was carried out to ensure that the materials had been submerged for a long period. Signs of submergence included the disappearance of bark, and algae growing on the surface of the substrate (Ho *et al*., 2001). Samples were returned to the laboratory, cut into approximately 20-30 cm long sections and incubated in sealed plastic bags. Moist tissues were added to the plastic bags to maintain a humid condition. Samples were then incubated at room temperature (20-30 C) under normal light conditions. After 1-2 weeks, the woody substrates were examined for the presence of fungi periodically over 2 months. Single spore isolations were made to following the method described by Choi *et al*. (1999). Materials supporting the fungi were air-dried and preserved as herbarium specimens in YNU.

Table 1. Water parameters at different sampling times.

	April 02	**July 02**	**October 02**	**January 03**
Temperature (C)	17.5	20	17	11
Water Temperature (C)	18	18	15	9
pH	8	8.6	7.2	6.9
Transparency (m)	0.17	0.2	0.15	0.4
Total Nitrates (mg/L)	2.35	2.4	2.09	0.77
Total Phosphates (mg/L)	0.118	0.217	0.104	0.074
Chl-*a* (mg/L)	47.32	197.17	89.08	38.48

Ecological analysis

The species-area curves were plotted for every collection to examine the sample size (Begon *et al*., 1993). The number of species and the occurrence were recorded and calculated. To compare the fungal communities among the four sampling periods, species richness and species abundance were calculated. Shannon-Weiner index (H′) was applied to evaluate the diversities of freshwater fungi, including species richness (N) and evenness (E). Sørensen's index of similarity (S′) was plotted and expressed with values between 0 (no similarity) and 1 (absolute similarity). The above data are calculated using the following formulas:

$$H' = -\sum_{i=1}^{s} Pi \log_e Pi$$

where $Pi = \dfrac{Ni}{N}$

$$E = \frac{N1}{S} = \frac{e^H}{S}$$

$$S' = \frac{2c}{a+b}$$

Ni = the number of *i*th species
N = the number of all species
Pi = the proportion of *i*th species
Log_e Pi = the natural logarithm of Pi
S = the total number of species in the community
a = total number of species from substrate 1 or site 1.
b = total number of species from substrate 2 or site 2.
c = number of common species to both substrata.

Results

Sample size

Species cumulative curves mostly reached asymptote (Fig. 1) before 100 samples and therefore 100 samples can provide a reasonable estimate of fungal communities from submerged woody substrates in this lake.

Fungal community in Lake Dianchi

The fungal taxa identified from all submerged woody substrates with their occurrence are listed in Table 2. The species richness, evenness, diversity index were calculated and are listed in Table 3. A total of 97 fungal taxa were identified on the woody substrata, comprising 56 ascomycetes and 41 anamorphic fungi (9 hyphomycetes and 32 coelomycetes).

The most common ascomycetes were from *Halosphaeriaceae* (35.5%), *Magnaporthaceae* (21.5%), *Lophiostomataceae* (11.5%) and *Lasiosphaeriaceae* (5.3%). Common ascomycete genera identified in this study were *Aniptodera*, *Massarina*, *Pseudohalonectria* and *Savoryella*, while *Dictyosporium*, *Phaeoisaria* and *Sporidesmium* were the most common anamorphic genera. Dominant species included *Savoryella lignicola* (19%), *Pseudohalonectria lignicola* (17%), *Phaeoisaria clematidis* (11%), *Aniptodera lignicola* (10%), *Dictyosporium heptasporum* (10%) and *Massarina thalassioidea* (10%).

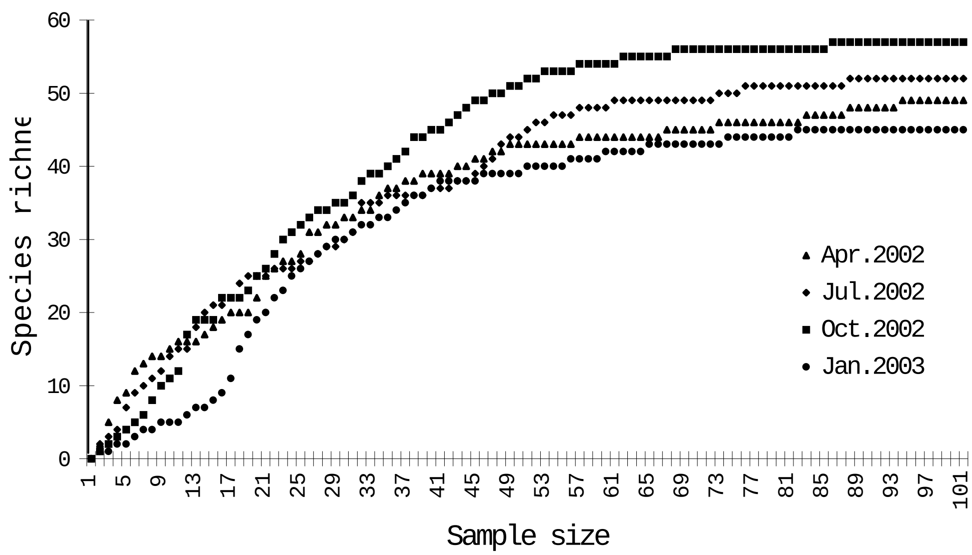

Fig. 1. Cumulative curves of fungi recorded in Lake Dianchi from different seasons.

Seasonal variation

The fungal communities identified at the four seasons on woody substrata at Lake Dianchi are compared in Table 3. The results show that the differences among the four collections are insignificant. The highest number of fungal taxa, 57 species, was collected in October 2002, followed by July 2002 (52 species), April 2002 (50 species) and January 2003 (45 species). *Pseudohalonectria lignicola* and *Savoryella lignicola* were the most dominant species at all of the sampling periods, with the exception of October 2002 when *Dictyosporium heptasporum* was most common. The fungal diversities from 4 sampling periods varied little (Shannon-Weiner indices varied from 3.155 to 3.681). Fifteen species were found from all four collections, indicating a similarity among these communities.

Fungal community on different monocotyledonous substrates

The occurrence and a comparison of fungi identified on bamboo, *Pennisetum purpurreum* and *Phragmites australis* are provided in Table 5 and Table 6. The species richness and diversity on *Pennisetum purpurreum* (N = 32, H′ = 3.082) was highest, followed by that from bamboo (N = 27, H′ = 2.889) and *Phragmites australis* (N = 21, H′ = 2.679). *Aniptodera lignicola* (10%), *Dictyosporium heptasporum* (8%) and *Pseudohalonectria lignicola* (8%) were dominant on *Pennisetum purpurreum*. *Massarina phragmiticola* (12%), *Phaeoisaria clematidis* (9%) and *Dactylaria longidentata* (7%) were dominant on *Phragmites australis*. *Savoryella lignicola* (23%), *Sporidesmium paludosum* (10%) and *Astrosphaeriella papillata* (8%) were dominant on bamboo. In comparing the six most frequent species, *Ellisembia repentioriunda* and *Pseudohalonectria lignicola* were common to all. Twelve species were common to all monocotyledons. Thirteen species were recorded only from *Pennisetum purpurreum*, seven only from bamboo and six only from *Phragmites australis*. Many species on monocotyledons were found to overlap with those on woody samples; 91% of species identified from random woody samples could be found on *Pennisetum purpurreum*, whereas 86% were on *Phragmites australis* and 93% on bamboo. As a result, each substrate supported different mycota but host specificity may be insignificant.

Discussion

Fungal communities

Lake Dianchi has some widely distributed freshwater fungi, such as *Aniptodera chesapeakensis*, *Massarina thalassioidea*, *Pseudohalonectria lignicola* and *Savoryella lignicola* (Shearer, 1993; Cai *et al*., 2003a). As well as these widely distributed species, 10 taxa are common to those found in other lakes in temperate regions (Shearer, 1993; Cai *et al*., 2002). Thirteen taxa previously reported from tropical regions, e.g. *Aniptodera lignicola, Ascotaiwania palmicola* and *Savoryella aquatica* (Hyde *et al*., 1999; Cai *et al*., 2003a), were also identified in this lake. Annulatascaceous species, which are common in tropical and subtropical regions (Hyde *et al*., 1997), were however

Table 2. The occurrence of fungi at different seasons in Lake Dianchi.

Taxa	Occurrence				Total occurrence
	Apr. 2002	**Jul. 2002**	**Oct. 2002**	**Jan. 2003**	
Ascomycetes					374
Annulatascaceae					2
Annulatascus sp.	-	-	1	-	1
Fluminicola bipolaris S.W. Wong, K.D. Hyde & E.B.G. Jones	1	-	-	-	1
Apiosporaceae					2
Apiospora sinensis K.D. Hyde, J. Fröhl. & Joa E. Taylor	1	1	-	-	2
Halosphaeriaceae					142
Aniptodera aquadulcis (S.Y. Hsieh, H.S. Chang & E.B.G. Jones) J. Campb., J. Anderson & Shearer	-	-	1	-	1
Aniptodera chesapeakensis Shearer & M.A. Mill.	1	2	-	-	3
Aniptodera lignicola K.D. Hyde, W.H. Ho & K.M. Tsui	11	9	4	6	30
Aniptodera mauritaniensis K.D. Hyde, W.H. Ho & K.M. Tsui	2	4	-	-	6
Aniptodera palmicola K.D. Hyde, W.H. Ho & K.M. Tsui	1	1	-	1	3
Halosphaeria cucullata (Kohlm.) Kohlm.	3	-	-	1	4
Natantispora retorquens (Shearer & J.L. Crane) J. Campb., J.L. Anderson et Shearer	1	-	-	-	1
Phaeonectriella lignicola R.A. Eaton & E.B.G. Jones	-	-	2	-	2
Nais inornata Kohlm	1	-	-	-	1
Savoryella aquatica K.D. Hyde	1	7	2	2	12
Savoryella curvispora W.H. Ho, K.D. Hyde & Hodgkiss	2	1	-	-	3
Savoryella lignicola E.B.G. Jones & R.A. Eaton	21	18	13	24	76
Hypocreaceae					9
Nectria sp.	5	4	-	-	9
Lasiosphaeriaceae					21
Cercophora sp. 1	2	2	2	1	7
Cercophora sp. 2	-	-	2	-	2
Lasiosphaeria sp.	-	-	1	1	2
Lasiosphaeria breviseta P. Karst.	-	2	-	-	2
Podospora sp. 1	-	2	-	-	2
Podospora sp. 2	-	1	1	-	2
Zopfiella latipes (N. Lundq.) Malloch & Cain	-	-	3	1	4

Table 2 continued. The occurrence of fungi at different seasons in Lake Dianchi.

Taxa	Occurrence April 2002	July 2002	Oct. 2002	Jan. 2003	Total occurrence
Leptosphaeriaceae					1
Ophiobolus sp.	-	1	-	-	1
Lophiostomataceae					46
Lophiostoma bipolare K.D. Hyde	4	-	1	1	6
Lophiostoma proprietunicatum K.M. Tsui, K.D. Hyde & Hodgkiss	1	-	-	3	4
Lophiostoma sp. 1	-	1	1	1	3
Massarina thalassioidea K.D. Hyde & Aptroot	9	4	4	13	30
Massarina sp. 1	-	-	1	-	1
Massarina sp. 2	-	1	1	-	2
Magnaporthaceae					86
Ophioceras arcuatissporum Shearer, J.L. Crane & W. Chen	-	1	-	-	1
Ophioceras commune Shearer, J.L. Crane & W. Chen	1	-	2	-	3
Ophioceras dolichostomum (Berk. & M.A. Curtis) Sacc.	4	7	-	1	12
Pseudohalonectria adversaria Shearer	-	-	1	1	2
Pseudohalonectria lignicola Minoura & T. Muroi	25	15	9	19	68
Massariaceae	7				
Caryospora callicarpa (Curr.) Nitschke ex Fuckel	-	2	-	-	2
Caryospora minima Jeffers	3	-	1	1	5
Melanommataceae	8				
Astrosphaeriella papillata K.D. Hyde & J. Fröhl.	3	1	1	1	6
Astrosphaeriella stellata (Pat.) Sacc.	1	1	-	-	2
Phaeosphaeriaceae	3				
Phaeosphaeria sp. 1	-	1	-	-	1
Phaeosphaeria sp. 2	-	1	1	-	2
Pleomassariaceae	3				
Kirschsteiniothelia elaterascus Shearer	1	-	1	1	3
Pleosporaceae	3				
Pleospora sp. 1	-	1	-	-	1
Pleospora sp. 2	-	1	1	-	2
Sordariaceae	10				
Gelasinospora sp.	3	-	3	2	8
Gelasinospora retispora Cain	-	-	2	-	2

Table 2 continued. The occurrence of fungi at different seasons in Lake Dianchi.

Taxa	Occurrence				Total occurrence
	Apr. 2002	Jul. 2002	Oct. 2002	Jan. 2003	
Sporormiaceae					1
Sporormiella minimoides S.I. Ahmad & Cain		1	-	-	1
Valsaceae					10
Diaporthe sp.	1	4	3	2	10
Incertae sedis					20
Ascolacicola aquatica Ranghoo & K.D. Hyde	-	-	1	-	1
Ascotaiwania palmicola K.D. Hyde	-	3	1	1	5
Jahnula poonythii K.D. Hyde & S.W. Wong	-	2	1	-	3
Phomatospora berkeleyi var. *macropoda* Sacc.	2	1	-	1	4
Saccardoella minuta L. Cai & K.D. Hyde	-	-	1	-	1
Ascomycete sp. 1	-	-	3	-	3
Ascomycete sp. 2	-	-	2	-	2
Ascomycete sp. 3	-	-	1	-	1
Anamorphic fungi					228
Coelomycetes					40
Coelomycetes sp. 1	1	2	1	1	5
Coelomycetes sp. 2	7	-	2	1	10
Coelomycetes sp. 3	6	2	1		9
Coelomycetes sp. 4	-	3	-	1	4
Coelomycetes sp. 5	2	-	-	-	2
Coelomycetes sp. 6	1	-	-	-	1
Coelomycetes sp. 7	-	1	2	-	3
Phoma sp.	-	-	1-	-	1
Tiarosporella paludosa (Sacc. & Fiori) Höhn.	2	3		-	5
Hyphomycetes					188
Acrodictys erecta (Ellis & Everh.) M.B. Ellis	1	-	2	1	4
Alternaria sp.	-	-	1		1
Aquaphila albicans Goh, K.D. Hyde & W.H. Ho	1	-	-	-	1
Candelabrum brocchiatum Tubaki	1	3	-	-	4
Canalisporium variabile Goh & K.D. Hyde	-	-	1	-	1
Dactylaria hoogii R.F. Castañeda & W.B. Kendr.	-	-	1	1	2
Dactylaria longidentata Cazau, Aramb. & Cabello	6	-	5	4	15

Table 2 continued. The occurrence of fungi at different seasons in Lake Dianchi.

Taxa	Occurrence				Total occurrence
	Apr. 2002	Jul. 2002	Oct. 2002	Jan. 2003	
Dactylaria splendida R.F. Castañeda & W.B. Kendr.	-	-	1	-	1
Dactylaria triseptata (Matsush.) R.F. Castañeda & W.B. Kendr.	-	-	-	2	2
Dictyochaeta plovercovensis Goh & K.D. Hyde	-	-	-	1	1
Dictyosporium heptasporum Damon	7	5	10	8	30
Dictyosporium lakefuxianensis L. Cai &K.D. Hyde	-	1	2	1	4
Dictyosporium musae Photica, McKenzie & K.D. Hyde	1	-	2	1	4
Dictyosporium polystichum (Höhn.) Damon	1	-	-	1	2
Ellisembia adscendens Subram	-	2	-	1	3
Ellisembia repentioriunda Goh & K.D. Hyde	1	1	2	5	9
Fusarium sp.	-	1	-	-	1
Helicoma sp.	-	-	1	-	1
Helicomyces roseus Link	1	-	1	-	2
Penicillium sp.	1	1	-	-	2
Periconia byssoides	-	-	1	-	1
Periconia digitata (Cooke) Sacc.	1	1	-	-	2
Periconia sp.	1	3	3	4	11
Phaeoisaria clematidis (Fuckel) S. Hughes	4	11	8	10	33
Phaeoisaria sp.	-	-	-	1	1
Sporidesmium hyalospermum (Corda) S. Hughes	1	-	6	3	10
Sporidesmium paludosum M.B. Ellis	2	2	5	9	18
Sporoschisma saccardoi E.W. Mason & S. Hughes	-	-	-	2	2
Taeniollela rudis (Sacc.) S. Hughes	1	-	-	1	2
Torula herbarum (Pers.) Link	5	5	1	2	13
Verticillium sp.	1	-	-	1	2
Xylomyces chlamydosporus Goos, R.D. Brooks & Lamore	1	2	-	-	3
Total species			97		
Total collections			602		

rare in this lake. Previous studies have not commonly identified members of *Annulatascaceae* from large water bodies such as lakes, but have found them to be more common in pristine streams in rainforests (Hyde *et al*., 1997).

Table 3. Comparison of freshwater fungi at different sampling times.

Sampling time	2 Apr. 2002	7 Jul. 2002	18 Oct. 2002	29 Jan. 2003
Sample size	100	100	100	100
Number of ascomycetes	27	32	34	22
Number of anamorphic fungi	25	18	23	23
Average number of taxa per sample	1.68	1.52	1.35	1.47
Unique species	8	9	15	4
Overlapping species in four months	15			
Five most common species	*Pseudohalonectria lignicola* (25%) *Savoryella lignicola* (21%) *Aniptodera lignicola* (11%) *Massarina thalassioidea* (9%) Coelomycetes sp. 2 (7%)	*Savoryella lignicola* (18%) *Pseudohalonectria lignicola* (15%) *Phaeoisaria clematidis* (11%) *Aniptodera lignicola* (9%) *Ophioceras dolichostomum* (7%) *Savoryella aquatica* (7%)	*Savoryella lignicola* (13%) *Dictyosporium heptasporum* (10%) *Pseudohalonectria lignicola* (9%) *Phaeoisaria clematidis* (8%) *Sporidesmium hyalospermum* (6%)	*Savoryella lignicola* (24%) *Pseudohalonectria lignicola* (19%) *Massarina thalassioidea* (13%) *Phaeoisaria clematidis* (10%) *Sporidesmium paludosum* (9%)
R	52	50	57	45
E	0.558	0.643	0.696	0.521
H´	3.368	3.471	3.681	3.155

Seasonal variation

Seasonal changes in the temperature have been shown to effect species richness and diversity (Suberkropp, 1984). In this study, differences in fungal communities and richness at different seasons were insignificant even though the summer and winter are distinct (high versus low rainfall) in the Kunming region (Whitmore *et al*., 1997). One reason for the insignificant differences may be the narrow temperature range in the lake (9-18 C) throughout the year. In temperate regions, the aquatic fungal communities have been found to be effected by variations in temperature (Shearer, 1972; Iqbal and Webster, 1977; Suberkropp, 1984). Another reason for the insignificant differences may be that Lake Dianchi is surrounded by farmland and there are few plants growing along its banks. In this area, forest cover rate is less than 28.6% (Jin, 2003b). Riparian vegetation had been regarded as an important factor influencing freshwater fungal communities (Fabre, 1996; Tsui *et al*., 2000). Because of the

Table 4. Comparison of fungal communities and diversities in similar studies.

Location	Lake Fuxian	Lake Dianchi	Lake Barrine	Plover Cover Reservoir
Climate	Subtropical	Subtropical	Tropical	Subtropical
Sampling time	April 2001	April 2002	April 1996	November 1996
Number of ascomycetes	35	27	14	17
Number of discomycetes	-	-	1	-
Number of anamorphic fungi	29	25	20	40
Average number taxa per sample	1.60	1.68	1.4	2.40
Three most common species	*Dictyosporium heptasporum* (15%) *Aniptodera chesapeakensis* (10%) *Savoryella lignicola* (9%)	*Pseudohalonectria lignicola* (25%) *Savoryella lignicola* (21%) *Aniptodera lignicola* (11%)	*Candelabrum brocchiatum* (41%) *Trichocladium linderi* (11%) *Canalisporium pulchrum* (9%)	*Kirschsteiniothelia elaterascus* (70%) *Didymella aptrootii* (14%) Unidentified coelomycete (12%)
R	64	52	35	57
E	0.704	0.558	0.495	0.436
H´	3.808	3.368	2.853	3.214

small numbers of lakeside plants, material entering the lake will vary little in species composition and quantity throughout the year. Therefore the low plant diversity and seasonal availability of detritus may account for minor variation of fungal communities in Lake Dianchi. Compared with streams, lakes are not suffering significant seasonal variations in water quantity and flow. In streams, the flow of water can vary largely during various seasons, from being dry to slow moving during the dry season, to rapidly moving during spates in the wet season. As a result, large differences in fungal communities may occur (Lamore and Goos, 1978; Ho *et al*., 2002). Nevertheless, Lake Dianchi is a large lentic habit, the volume of water is relatively constant and water movement is placid in this lake.

Comparison with previous studies

The fungal communities and diversity in Lake Barrine, Lake Dianchi, Lake Fuxian and Plover Cove Reservoir are compared in Table 4. The species

Table 5. Occurrences of fungi from different substrata collected in this study.

Taxa	Occurrence		
	Phragmites australis	***Pennisetum purpurreum***	**Bamboo**
Ascomycetes			
Aniptodera lignicola K.D. Hyde, W.H. Ho & K.M. Tsui	-	12	3
Aniptodera palmicola K.D. Hyde, W.H. Ho & K.M. Tsui	-	1	1
Ascotaiwania palmicola K.D. Hyde	4	1	-
Astrosphaeriella papillata K.D. Hyde & J. Fröhl.	-	-	8
Caryospora minima Jeffers	-	-	1
Cercophora sp. 1	-	1	-
Gelasinospora sp.	-	-	1
Hadrospora fallax (Mouton) Boise	-	1	-
Halosphaeria cucullata (Kohlm.) Kohlm.	1	-	1
Kirschsteiniothelia elaterascus Shearer	1	4	1
Lasiosphaeria sp.	-	1	-
Lophiostoma sp. 2	-	1	-
Massarina phragmiticola O.K. Poon & K.D. Hyde	13	-	-
Massarina thalassioidea K.D. Hyde & Aptroot	-	7	4
Natantispora retorquens (Shearer & J.L. Crane) J. Campb., J.L. Anderson et Shearer	3	-	-
Ophioceras dolichostomum (Berk. & M.A. Curtis) Sacc.	1	-	-
Pseudohalonectria lignicola Minoura & T. Muroi	6	8	5
Phomatospora berkeleyi var. *macropoda* Sacc.	-	1	-
Savoryella aquatica K.D. Hyde	-	2	5
Savoryella lignicola E.B.G. Jones & R.A. Eaton	3	6	19
Zopfiella latipes (N. Lundq.) Malloch & Cain	-	-	1
Anamorphic fungi	-	-	-
Coelomycetes			
Coelomycetes sp. 1	2	2	1
Coelomycetes sp. 2	1	-	7
Coelomycetes sp. 4	2	-	-

Table 5 continued. Occurrences of fungi from different substrata collected in this study.

Taxa	Occurrence		
	Phragmites australis	***Pennisetum purpurreum***	**Bamboo**
Coelomycetes sp. 7	-	1	-
Hyphomycetes			
Acrodictys erecta (Ellis & Everh.) M.B. Ellis	-	1	-
Alternaria sp.	-	1	-
Dactylaria longidentata Cazau, Aramb. & Cabello	9	7	3
Dactylaria splendida R.F. Castañeda & W.B. Kendr.	-	2	-
Dactylaria triseptata (Matsush.) R.F. Castañeda & W.B. Kendr.	5	-	-
Dictyochaeta plovercovensis Goh & K.D. Hyde	-	1	-
Dictyosporium heptasporum Damon	3	10	2
Dictyosporium lakefuxianensis L. Cai & K.D. Hyde	-	1	-
Dictyosporium musae Photita, McKenzie & K.D. Hyde	-	-	2
Dictyosporium polystichum (Höhn.) Damon	-	3	-
Ellisembia adscendens Subram.	-	-	1
Ellisembia repentioriunda Goh & K.D. Hyde	7	8	5
Periconia minutissima Corda	1	5	1
Pleurophragmium simplex (Berk. & Broome) S. Hughes	1	-	-
Phaeoisaria clematidis (Fuckel) S. Hughes	10	3	7
Pseudospiropes sp.	-	-	1
Sporidesmium hyalospermum (Corda) S. Hughes	6	1	3
Sporidesmium paludosum M.B. Ellis	5	7	9
Sporoschisma saccardoi E.W. Mason & S. Hughes	1	1	4
Taeniolella rudis (Sacc.) S. Hughes	-	4	-
Torula herbarum (Pers.) Link	-	1	2
Verticillium sp.	-	1	1

Table 6. Comparison of taxonomic composition and diversities among substrata collected in this study.

Substrate	***Phragmites australis***	***Pennisetum purpurreum***	**Bamboo**
Sample size	100	100	100
Ascomycetes	8	13	12
Anamorphic taxa	13	19	15
Total number of species	21	32	27
Average number species per sample	0.81	1.06	0.99
Number of unique species from one kind of substrate	6	13	7
Six most frequent species	*Massarina phragmiticola* (13%) *Phaeoisaria clematidis* (10%) *Dactylaria longidentata* (9%) *Ellisembia repentioriunda* (7%) *Pseudohalonectria lignicola* (6%) *Sporidesmium hyalospermum* (6%)	*Aniptodera lignicola* (12%) *Dictyosporium heptasporum* (10%) *Pseudohalonectria lignicola* (8%) *Ellisembia repentioriunda* (8%) *Dactylaria longidentata* (7%) *Massarina thalassioidea* (7%) *Sporidesmium hyalospermum* (7%)	*Savoryella lignicola* (19%) *Sporidesmium paludosum* (9%) *Astrosphaeriella papillata* (8%) Coelomycetes sp.2 (7%) *Ellisembia repentioriunda* (5%) *Phaeosaria clematidis* (7%) *Pseudohalonectria lignicola* (5%) *Savoryella aquatica* (5%)
H´	2.679	3.082	2.889

richness (N = 64 species), evenness (E = 0.704) and diversity index (H´ = 3.808) in Lake Fuxian was highest. Higher species evenness account for higher diversity in Lake Dianchi (E = 0.558, H´ = 3.368) than in the Plover Cove Reservoir (E = 0.436, H´ = 3.214), although more taxa were identified in the Plover Cove Reservoir (57 species) than in Lake Dianchi (52 species). Lowest species richness (35 species) and diversity (H´ = 2.853) were found in Lake Barrine.

Pseudohalonectria lignicola (25%), *Savoryella lignicola* (21%) and *Aniptodera lignicola* (11%) were dominant in Lake Dianchi, while *Dictyosporium heptasporum* (15%), *Savoryella lignicola* (10%) and *Aniptodera chesapeakensis* (9%) were dominant in Lake Fuxian; *Kirschsteiniothelia elaterascus* (70%), *Didymella aptrootii* (14%) and an unidentified coelomycete (12%) were dominant in Plover Cove Reservoir; *Candelabrum brocchiatum* (41%), *Trichocladium linderi* (11%), and *Canalisporium pulchrum* (9%) were dominant in Lake Barrine. Of the three most common species identified in these water bodies, only *Savoryella lignicola* overlapped between Lake Dianchi and Lake Fuxian.

There are some overlapping species between fungi in Lake Dianchi and that in other lakes and reservoirs; Lake Barrine, North Queensland (9 overlapping species), Plover Cover Reservoir, Hong Kong (11 overlapping species), Lake Fuxian, Yunnan, China (15 overlapping species) (Hyde and Goh, 1998; Goh and Hyde, 1999; Cai *et al*., 2002). Lake Dianchi shares more fungal species with Lake Fuxian than with other water bodies, most likely because of the similar geographic location and climate in this region. Fungal communities in similar geographic locations or similar climatic regions are often more similar than those in unrelated geographic locations or different climatic regions (Wong *et al*., 1998; Fröhlich and Hyde, 2000).

Differences in fungal communities in Lake Fuxian and Lake Dianchi and possible pollution effects

The fungal communities in Lake Fuxian in Spring 2002 (Cai *et al*., 2002) are compared with those in Lake Dianchi in Spring 2003 (Table 4). Lake Fuxian is a clean plateau lake (TP = 0.0098mg/L, TN = 0.15 mg/L, SD = 7.10m, COD_{Mn} = 0.80 mg/L, BOD_5 = 0.57 mg/L, TSI_G = 25.98) located 17 kilometers from Lake Dianchi and the waters are mainly at the oligo-trophic level (Jin, 2003a). A slightly higher fungal diversity was recorded in Lake Fuxian (Table 4). There were, however, large differences in fungal communities in these lakes (similarity index = 0.337). There were only 15 species common to both lakes in the spring collections. Fifty-two species were only found in Lake Fuxian, while 37 species were unique to Lake Dianchi. Less species richness, uneven species distribution and higher species abundance, especially for those dominant species were found in Lake Dianchi. Various factors, such as the different riparian vegetation (varied and abundant around Lake Fuxian, poor and sparse around Lake Dianchi) and different pollution level (Lake Dianchi is higher polluted, TP and TN are nearly 10 times of that in Lake Fuxian) between these two lakes, are suggested to cause the differences in fungal communities. Pollution has been shown to cause changes in fungal communities but have little effect on fungal diversity (Tsui *et al*., 2001a,b).

There was little difference in the occurrence and diversity of aquatic hyphomycetes (excluding Ingoldian Fungi) in Lake Dianchi and Lake Fuxian. The ascomycetes in these lakes, however, differed, with more species often

Table 7. Indices of similarity (S´) between different substrata.

	Pennisetum purpurreum	**Bamboo**
Phragmites australis	0.491	0.583
Pennisetum purpurreum		0.610

associated with organic pollutants and sewage effluent (e.g. *Cercophora* sp., *Gelasinospora* sp., *Lasiosphaeria* sp., *Podospora* sp.) being recorded in Lake Dianchi. Tsui *et al*. (2001a,b) also found that *Cercophora* spp. became prevalent downstream in the Lam Tsuen River and Tai Po River, which were affected by human pollution. The occurrence of fungi, such as *Cercophora* and *Podospora* spp., which are usually associated with dung and other organic substrata (Bell, 1983), may indicate that the water quality has deteriorated due to organic enrichment. This study and the study of Tsui *et al*. (2001a,b) indicate relationships between the occurrence of certain fungi and polluted water environments. Further studies may be helpful to provide bio-indicators of water quality.

Host recurrence

In this study, the dominant species and distribution patterns of taxa among three monocotyledonous hosts indicated that substrate may have an affect on fungal distribution in freshwater environments. Similar relationships between saprobic fungi and their hosts have also been found in other studies (e.g. Sarma *et al*., 2001; Wong and Hyde, 2001). Previous studies of fungi on substrates in aquatic environments have recorded no or low host-specificity (Shearer and Bodman, 1983; Shearer and Webster, 1991; Gönczöl and Révay, 1993). In this study, the relatively high similarity index (0.491-0.610) of fungi on the three monocotyledons, also indicate a lack of host-specificity (Table 7). Species unique to a single host in this study have previously been recorded on other hosts in other studies (Wong and Hyde, 2001, 2002; Hyde *et al*., 2002). Within the 6 most dominant species on *Phragmites australis* and *Pennisetum purpurreum*, 4 species are shared by them (*Dactylaria longidentata, Ellisembia repentioriunda, Pseudohalonectria lignicola* and *Sporidesmium hyalospermum*). While *Phragmites australis* and the bamboo substrate share 3 species (*Phaeoisaria clematidis, Ellisembia repentioriunda, Pseudohalonectria lignicola*). These results have shown that the host specificity is insignificant since the competitive spp. can overcome the effect of host variation. On the other hand, certain taxa do occur more often on a particular host (e.g.

Massarina phragmiticola on *Phragmites australis*), which can be regarded as host recurrent (*sensu* Zhou and Hyde, 2001).

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