Diurnal fluctuation of spores of freshwater hyphomycetes in two tropical streams

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Diurnal changes in species and spore richness of freshwater hyphomycetes in relation to physicochemical features in two streams of the southwest India were compared using Millipore filtration during the post-monsoon season. Drift spores belonging to 16–19 species were recorded. *Anguillospora longissima, Flagellospora curvula, Lunulospora curvula* and *Triscelophorus monosporus* were dominant in both streams. The Pearson correlation revealed significant negative correlation between temperature and dissolved oxygen ($p < 0.01$) in both streams. The water temperature, pH and conductivity decreased between day and night, while the dissolved oxygen became elevated. Total species showed two peaks at 12 hr intervals (9 am and 9 pm) in both streams. The species richness, diversity and evenness were higher during the night than day in the Konaje stream, while it was reverse in the Mallapura stream. The species richness of both streams has no significant correlation with water quality. The total spores exhibited two peaks at 15 hr intervals (3 pm and 6 am) in both streams. The total spores differed significantly ($p < 0.001$) between streams and was higher during the night than day in both streams, possibly due to lack of leaf shredding invertebrates. Among the five dominant species, peak spore production of *Lunulospora curvula* in both streams coincided with the peaks of total spores. The spore richness in the Konaje stream had no significant correlation with water parameters, but showed significant negative correlation with temperature in the Mallapura stream ($p < 0.05$). This study revealed contrasting results in diurnal fluctuation of spores of freshwater hyphomycetes compared to temperate region.

Key words – diurnal periodicity – freshwater hyphomycetes – Millipore filtration – spore concentration – water quality

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Introduction

The freshwater hyphomycetes are also known as Ingoldian fungi, which are involved in turnover of submerged leaf litter in streams and generate characteristic spores for dispersal (Ingold 1942). The spatial and temporal changes of freshwater hyphomycetes have been studied by sampling drift spores and spores trapped by foam from different parts of the world (e.g. Subarctic: Müller-Haeckel & Marvanová 1979, Germany: Bärlocher & Rosset 1981, England: Shearer & Webster 1985, New Zealand: Aimer & Segedin 1985, Canada: Bärlocher 1987, Austraila: Thomas et al. 1989, 1991, 1992, India: Sridhar & Kaveriappa 1989, Rajashekhar & Kaveriappa 1993, Raviraja et al. 1998a,b, France: Chauvet 1991, Fabre 1997, 1998, Hungary: Gönczöl &

Révay 1999) These studies revealed that the spore fluctuation in water dependent on changes in leaf litter input and physicochemical features of waters. Freshwater hyphomycetes mainly exploit the seasonally supplied leaf litter. However, such substrates also constitute an important source of nutrition to the leaf-shredding invertebrates (especially after fungal growth) leading to deteriorate the potentiality of fungi to produce spores (Bärlocher 2009). Hence, these fungi have adapted ruderal strategy to capture resource and swiftly reproduce asexually to catch the new substrate. Over 50% of mycelial biomass will be invested by the freshwater hyphomycetes for the production of conidia (Findlay & Arsuffi 1989, Maharning & Bärlocher 1996, Chauvet & Suberkropp 1998). It is evident that the mycelia will be converted into spores especially when external supplies of N and P become limited (Sridhar & Bärlocher 2000). The successive pattern of arrival rates of spores on substrates, the rate of spore release from substrates and fungal biomass of freshwater hyphomycetes in leaf litter exposed to a stream is called 'boom-bust cycle' (Bärlocher 2009). The changes in water quality as well as the supply of leaf litter will drastically alter this cyclic event in lotic ecosystems.

Besides studies on spatial and temporal fluctuations of freshwater hyphomycetes, the diurnal changes in spore concentration in temperate regions have also been investigated by Thomas et al. (1991, 1992). In the Lees creek of Australia with constant water flow and constant temperature regime found increased spore load during the afternoon when compared to the morning (Thomas et al. 1991). They predicted that most of the spores collected during the early morning might have been developed during the night followed by further development of spores during day, which peaked during the afternoon. Thomas et al. (1992) could not attribute the diurnal spore periodicity in their field-based experiment to an alternating light regime. However, to our knowledge there seems to be no studies on diurnal fluctuation of spores of freshwater hyphomycetes in the tropics. In the Western Ghats and west coast of India, species richness and spore load of freshwater hyphomycetes usually attains peak during the post-monsoon period (October-January) (Sridhar & Kaveriappa 1984, 1989, Sridhar et al. 1992). Therefore, the current study envisaged to evaluate diurnal periodicity of spores of freshwater hyphomycetes in two streams of the southwest India during post-monsoon season in relation to the physicochemical features of water by sampling on smaller time and space scales.

Methods

Study site

The experiment was conducted in Konaje stream adjacent to the Mangalore University Campus and Mallapura stream near Karwar. The Konaje stream (12°48′ N, 74°55′ E; ~65–75 m asl) is a second order stream with a rocky and sandy bottom located about 22 km towards southeast of Mangalore City, which flows through forest and plantations and joins the Arabian Sea. The common tree species lining the Konaje stream include: *Alstonia scholaris*, *Artocarpus integrifolius*, *Careya arborea*, *Ficus benghalensis*, *Holigarna ferruginea*, *Mangifera indica*, *Odina wodier*, *Syzygium caryophyllatum*, *Syzygium cumini* and *Terminalia paniculata*. The stream Mallapura (14°54′ N, 74°19 E; ~10–15 m asl) is also a second order stream with a rocky and sandy bottom situated about 30 km east of the Karwar City and joins the River Kali. The common riparian tree species of Mallapura stream include: *Artocarpus heterophyllus*, *Ficus benghalensis*, *Ficus recemosa*, *Syzygium caryophyllatum*, *Terminalia paniculata* and *Xylia xylocarpa*.

Sampling

During the post-monsoon season (Konaje: November 16–17, 2009; Mallapura: November 20–21, 2009), five sampling points at a distance of 10 m were selected in each stream. During these days, there was no precipitation in the catchments of both streams. The water samples from each sampling point were collected at three-hourly intervals beginning from 9 am up to 24 hours followed by an additional sampling at 9 am for assessment of physicochemical characteristics and filtration to trap drift spores of freshwater hyphomycetes. To assess the leaf shredding macroinvertebrates, the leaf packs were examined during each sampling.

Water analysis

Water temperature of samples collected from each sampling point was determined by mercury thermometer, while the pH, conductivity and total dissolved solids were assessed using a water analysis kit (Water Analyzer 371, Systronics, Gujarat, India). The fixed water samples were evaluated for dissolved oxygen by Winkler's method (APHA 1995).

Spore assessment

The water samples of 100 mL each were filtered through Millipore filters (diameter, 47 mm; porosity, 5 µm) on each sampling point and the filters were stained with aniline blue in lactophenol (Iqbal & Webster 1973). Stained filters were cut into half to mount on slides and screened (20–100 ×) to score the spores using a microscope (Nikon OPTIPHOT, Japan). The whole filter was screened for qualitative and quantitative assessment of spores.

Data analysis

One-way ANOVA (ORIGEN Pro 8.1) was employed to determine the diurnal difference in species and spore richness between the streams; species and spore richness between day and night; and water qualities between day and night. The Simpson and Shannon diversities and evenness of fungi during day and night were assessed according to Magurran (1988) and Pielou (1975). The relationship between species and spore richness vs. water qualities was assessed based on Pearson correlation (parameters: P values, two tailed; confidence intervals, 95%) (SPSS 6.0 Windows Student Ver 3.5).

Results

Changes in water quality

The mean water parameters between Konaje and Mallapura streams were narrow (Table 1). Between day and night, the water temperature, pH and conductivity dropped in both streams, while the dissolved oxygen rose (Table 2). Decrease in temperature and increase in dissolved oxygen between day and night was significant in the Koanje stream ($p < 0.001$). Significant decrease in temperature ($p < 0.01$) and pH ($p < 0.01$) was seen between day and night in the Mallapura stream, while the total dissolved solids significantly raised during night ($p < 0.001$). The Pearson correlation revealed a negative correlation between temperature and dissolved oxygen ($p < 0.01$) in both streams (Table 3). The total dissolved solids vs. conductivity in the Konaje stream was positively correlated ($p < 0.01$). The total dissolved solids vs. temperature in Mallapura stream was also negatively correlated ($p < 0.05$), while with dissolved oxygen it was positively correlated ($p < 0.05$). The leaf packs examined during each sampling were devoid of leaf shredding macroinvertebrates.

Fluctuation in species

On filtering water samples up to 24 hours, drift spores of 19 and 16 species of freshwater hyphomycetes were recovered in the Koanje and Mallapura streams respectively (Table 4). In both streams, *Anguillospora longissima*, *Flagellospora curvula, Lunulospora curvula, Triscelophorus monosporus* and *Anguillospora crassa* or *Triscelophorus acuminatus* were dominant. Total species showed two peaks at 12 hr intervals (9 am and 9 pm) in both streams and within 24 hours the species richness had almost doubled (Fig. 1). The species richness between the Konaje and Mallapura streams was not significantly different ($p = 0.09$). The species richness between day and night in the Konaje stream increased ($p = 0.87$), while it decreased in the Mallapura stream ($p = 0.73$) (Fig. 2). Between day and night, spores of 14 species increased and five species decreased in the Konaje stream (Table 4). In the Mallapura stream, spores of six species increased, seven species decreased and three species did not alter. The species richness of both streams did not show significant correlation with water parameters in both streams (Table 3).

Fluctuation in spores

The total spores showed two peaks at 15 hr intervals (3 pm and 6 am) in both streams (Fig. 1). The spore richness differed significantly ($p = 2.51 \times 10^{-4}$) between streams. It was higher during the night than day in both streams without significant difference (Konaje, $p = 0.27$, Mallapura, $p = 18$) (Fig. 2; Table 3)

Table 1. Physicochemical variables recorded during diurnal study at the Konaje and Mallapura (in parenthesis) streams (n = 5 ± SD).

Parameter	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM	3:00 AM	6:00 AM
Temperature (ºC)	28.4±0.17 (27.6±0.12)	29.1±0.23 (27.7±0.17)	28.8±0.12 (28.3±0.25)	28.0±0.1 (28.8±0.12)	28.0±0.15 (28.3±0.15)	27.9±0.15 (27.4±0.12)	27.9±0.06 (26.8±0.12)	27.9±0.06 (26.9±0.06)
pH	6.9±0.46 (6.9±0.42)	6.3±0.06 (6.4±0.10)	6.3±0.1 (6.4±0.25)	6.3±0.15 (6.3±0.12)	6.3±0.15 (6.2±0.06)	6.4±0.06 (6.1±0.06)	6.5±0.06 (6.2±0.27)	6.5±0.06 (6.3±0.20)
Conductivity (μS/cm)	5.7±0.41 (4.3±0.13)	5.2±0.35 (4.2±0.22)	4.8±0.16 (5.9±3.0)	4.9±0.08 (4.1±0.20)	5.0±0.30 (4.4±0.04)	4.9±0.17 (4.8±0.43)	4.9±0.20 (4.6±0.20)	5.0±0.12 (4.3±0.04)
Dissolved oxygen (mg/L)	7.5±0.06 (7.9±0.17)	7.4±0.27 (7.2±0.06)	7.6±0.35 (7.1±0.06)	7.5±0.2 (7.2±0.06)	7.8±0.12 (7.2±0.21)	7.9±0.17 (7.9±0.15)	7.9±0.23 (7.9±0.10)	8.0±0.06 (7.6±0.27)
Total dissolved solids (mg/L)	2.5±0.21 (1.9±0.06)	2.3±0.15 (1.9±0.09)	2.1±0.07 (1.8±0.01)	2.2±0.04 (1.9±0.10)	2.2±0.13 (2.0±0.01)	2.2±0.08 (2.2±0.19)	2.2±0.09 (2.1±0.09)	2.3±0.05 (2.0±0.02)

Table 2. Mean physicochemical variables during day night at the Konaje and Mallapura streams (range in parenthesis) (n = 20, mean ± SD)

Parameter	Konaje stream		Mallapura stream		Mean of day and night (n = 40 ± SD)	
	Day	Night	Day	Night	Konaje stream	Mallapura stream
Temperature (ºC)	28.56±0.42[a] (27.9–29.2)	27.94±0.11[b]** (27.7–28.2)	28.09±0.48[a] (27.5–28.9)	27.37±0.62[b]* (26.7–28.5)	28.3±0.44 (27.7–29.2)	27.7±0.66 (26.7–29.2)
pH	6.47±0.32[a] (6.2–7.4)	6.41±0.11[a] (6.1–6.5)	6.5±0.32[a] (6.1–7.4)	6.2±0.15[b]* (6–6.5)	6.4±0.24 (6.2–7.4)	6.4±0.29 (6–7.4)
Conductivity (μS/cm)	5.15±0.43[a] (4.82–6.17)	4.93±0.17[a] (4.63–5.22)	4.65±1.43[a] (3.91–9.37)	4.52±0.26[a] (4.27–4.74)	5.0±0.35 (4.63–6.17)	4.6±1.03 (3.91–9.37)
Dissolved oxygen (mg/L)	7.50±0.22[a] (7.3–8)	7.89±0.14[b]** (7.6–8)	7.36±0.33[a] (7.1–8)	7.63±0.33[a] (7–8)	7.7±0.27 (7.3–8)	7.5±0.36 (7–8)
Total dissolved solids (mg/L)	2.28±0.18[a] (2.06–2.74)	2.21±0.08[a] (2.06–2.27)	1.88±0.07[a] (1.79–1.99)	2.05±0.11[b]** (1.96–2.37)	2.2±0.14 (2.06–2.74)	2.0±0.13 (1.79–2.37)

Figures across the columns with different letters are significantly different (*$p < 0.01$, **$p < 0.001$; one-way ANOVA)

Table 3. Pearson correlation coefficients between species richness/spore richness vs. physicochemical features of the Konaje and Mallapura (in parenthesis) streams.

	Temperature	pH	Conductivity	Dissolved oxygen	Total dissolved solids
Species richness	–0.119 (0.008)	0.036 (0.098)	–0.242 (0.190)	–0.090 (0.088)	–0.180 (–0.224)
Spore richness	–0.200 (–0.449*)	–0.041 (0.194)	0.091 (–0.060)	0.269 (0.284)	0.156 (0.165)
	Temperature	–0.095 (0.059)	0.266 (0.166)	–0.546** (–0.745**)	0.171 (–0.443*)
		pH	0.318 (–0.055)	–0.093 (0.197)	0.303 (–0.379)
			Conductivity	–0.239 (–0.145)	0.985** (–0.009)
				Dissolved oxygen	–0.168 (0.474*)

*Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)

The spore richness of the most dominant species *Lunulospora curvula* also did not differ significantly between day and night in both streams (Konaje, $p = 0.10$, Mallapura, $p = 0.07$). *Lunulospora curvula* showed two peaks (3 or 6 pm and 6 or 9 am) in both streams coinciding with the peaks of total spores (Fig. 3). The Simpson and Shannon diversities and evenness were higher during night than day in the Konaje stream, while it was reverse in the Mallapura stream (Table 4). The spore richness of the Konaje stream did not show significant correlation with water parameters, but it showed a significant negative correlation with temperature in the Mallapura stream ($p < 0.05$).

Discussion

The biomass of freshwater hyphomycetes constitutes up to 17% of total detritus mass and more than 50% of mycelial biomass will be invested for production of spores (Suberkropp 1984, 1991, 1995, Findlay & Arsuffi 1989, Maharning & Bärlocher 1996, Gessner 1997, Chauvet & Suberkropp 1998). Thus, released spores in flowing waters indirectly represent the fungal biomass. Several techniques have been employed to trap drift spores of freshwater hyphomycetes (e.g. membrane filtration, rosin-coated slides, cellophane and Plexiglass slides) (Iqbal & Webster 1973, Bärlocher 1987, Lindsey & Glover 1976, Müller-Haeckel & Marvanová 1979). Such methods are better to assess overall spores than assessing foam samples in view of accumulation of more multiradiate spores or easily trappable spores including several washed out terrestrial spores in foam (Lindsey & Glover 1976, Iqbal & Webster 1993, Bärlocher 1992; Gessner et al. 2003). Population dynamics of freshwater hyphomycetes have been studied based on drift spores (e.g. Müller-Haeckel & Marvanová 1979, Shearer & Lane 1983, Aimer & Segedin 1985, Shearer & Webster 1985, Thomas et al. 1989, Fabre 1998, Gönczöl & Révay 1999, Gönczöl et al. 2001). Drift spores reach a peak usually during the late summer and or autumn in several temperate streams coinciding with leaf litter deposition. In the streams of Western Ghats and west coast of India, the spore population reached a peak after summer or monsoon through post-monsoon period coinciding with leaf litter input (e.g. Sridhar & Kaveriappa 1984, 1989, Chandrashekar et al. 1990, Sridhar et al. 1992).

Studies on diurnal fluctuation of spore concentration of freshwater hyphomycetes by Thomas et al. (1991, 1992) in temperate stream projected interesting results. The spore load was elevated (up to 17%) as the day progressed and the afternoon collections were significantly higher than the morning collections (Thomas et al. 1991). Based on the supply of substrata in

Table 4. Fluctuation of spores/100 mL in stream waters between day and night (n = 20, mean ± SE).

Taxon	Konaje stream		Mallapura stream		Increase/Decrease
	Day	Night	Day	Night	(Konaje/Mallapura)*
Lunulospora curvula Ingold	36.3±3.1	63.9±12.8	17.2±3.3	24.1±3.2	+/+
Flagellospora curvula Ingold	36.9±3.7	33.1±2.9	4.7±1.8	7.0±0.4	–/+
Triscelophorus monosporus Ingold	5±2.5	12.1±3.9	2.3±1.0	1.3±0.4	+/–
Anguillospora longissima (Sacc. &P. Syd.) Ingold	5.2±0.9	5.7±1.9	2.4±0.5	2.8±0.7	+/+
Anguillospora crassa Ingold	0.2±0.2	0	4.8±1.6	4.5±1.7	–/–
Triscelophorus acuminatus Nawawi	0.7±0.4	7.4±4.2	0.3±0.3	0.3±0.2	+/0
Flagellospora penicillioides Ingold	3.7±0.9	0.9±0.6	2±1.8	0.5±0.3	–/–
Cylindrocarpon sp.	0	0.2±0.2	0	2.8±1.1	+/+
Helicomyces roseus Link	0	1.9±0.6	0	0.2±0.2	+/+
Ingoldiella hamata D.E. Shaw	0.2±0.2	1.8±1.2	0	0	+/0
Condylospora spumigena Nawawi	0.4±0.2	0.9±0.8	0.5±0.3	0	+/–
Clavariana aquatica Nawawi	0.3±0.3	0.7±0.4	0.2±0.2	0	+/–
Triscelophorus konajensis K.R. Sridhar & Kaver.	0.2±0.2	0.5±0.3	0.2±0.2	0.2±0.2	+/0
Lunulospora cymbiformis K. Miura	0.4±0.2	0	0.3±0.2	0.3±0.2	–/0
Wiesneriomyces laurinus (Tassi) P.M. Kirk	0	0.7±0.6	0.3±0.2	0	+/–
Phalangispora constricta Nawawi & J. Webster	0	0.9±0.8	0	0	+/0
Synnematospora constricta K.R. Sridhar & Kaver.	0.5±0.5	0	0.3±0.2	0	–/–
Flabellospora verticillata Alas.	0	0.3±0.2	0	0.2±0.2	+/+
Tricladium splendens Ingold	0	0.2±0.2	0	0	+/0
Total species	14	16	13	12	+/–
Total conidia	89.8±9.2	131.0±25.1	35.5±4.9	43.9±5.7	+/+
Simpson diversity	0.933	0.945	0.946	0.937	+/–
Simpson evenness	0.716	0.731	0.780	0.718	+/–
Shannon diversity	3.700	4.000	3.700	3.585	+/–
Shannon evenness	0.530	0.559	0.659	0.604	+/–

* +, Increase; –, Decrease; 0, No change

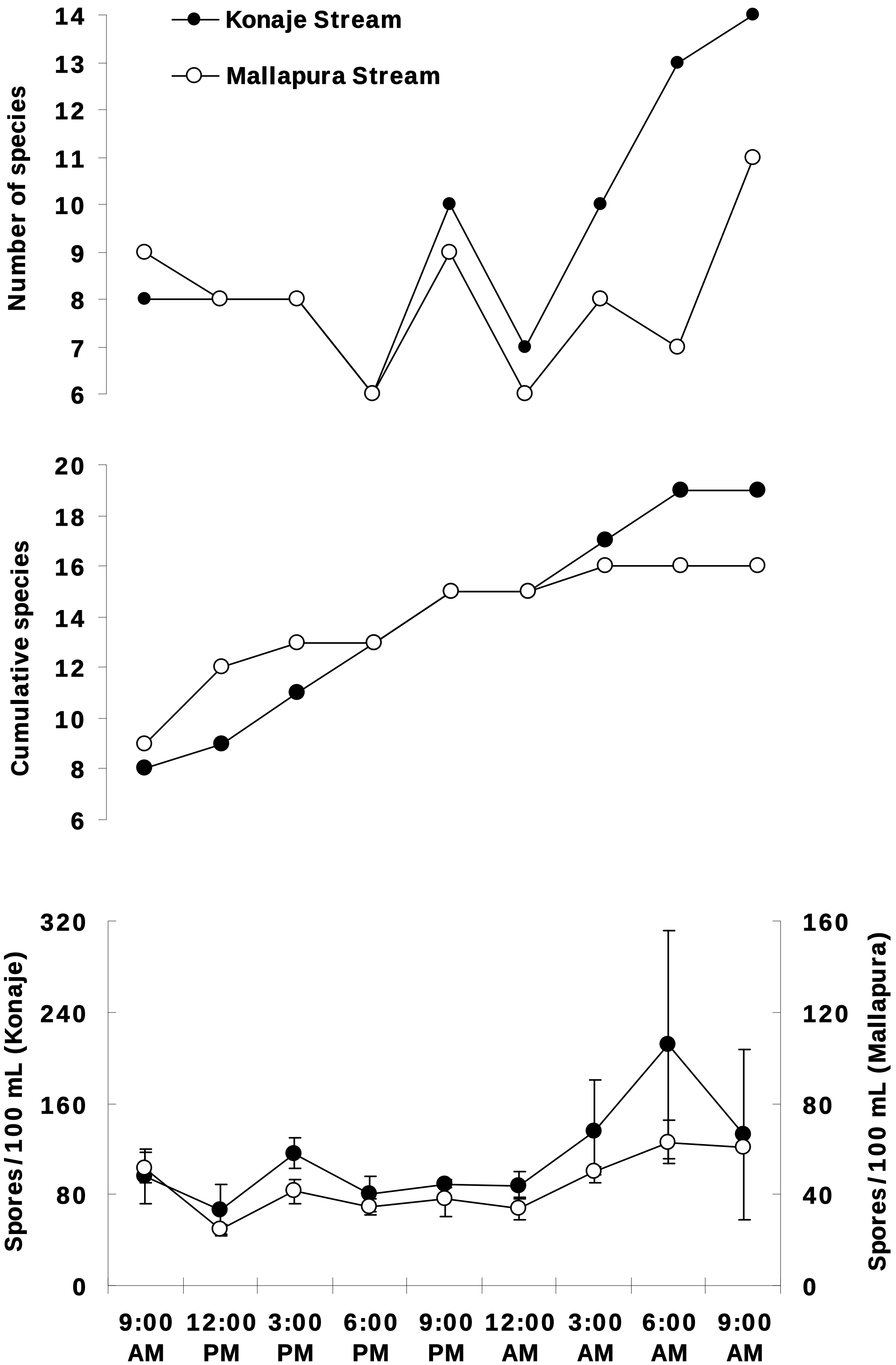

Fig. 1. – Diurnal fluctuation of species (n=5, mean), cumulative species (n = 5, mean) and diurnal fluctuation of spores (n=5, mean±SE) of freshwater hyphomycetes in the Kanaje and Mallapura streams.

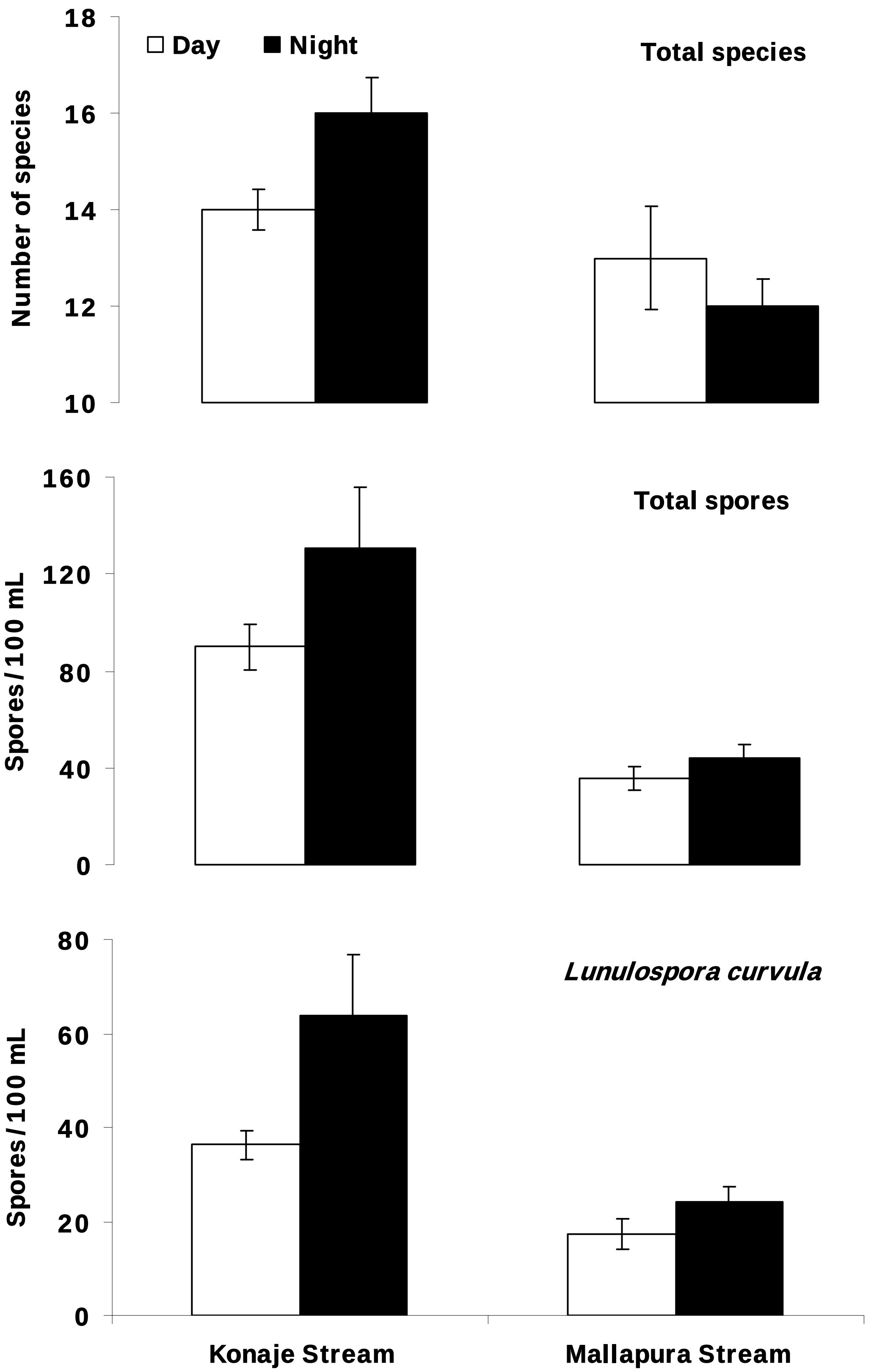

Fig. 2. – Fluctuation of species, total spores and spores of *Lunulospora curvula* during day and night in the Konaje and Mallapura streams (n = 20, mean ± SE).

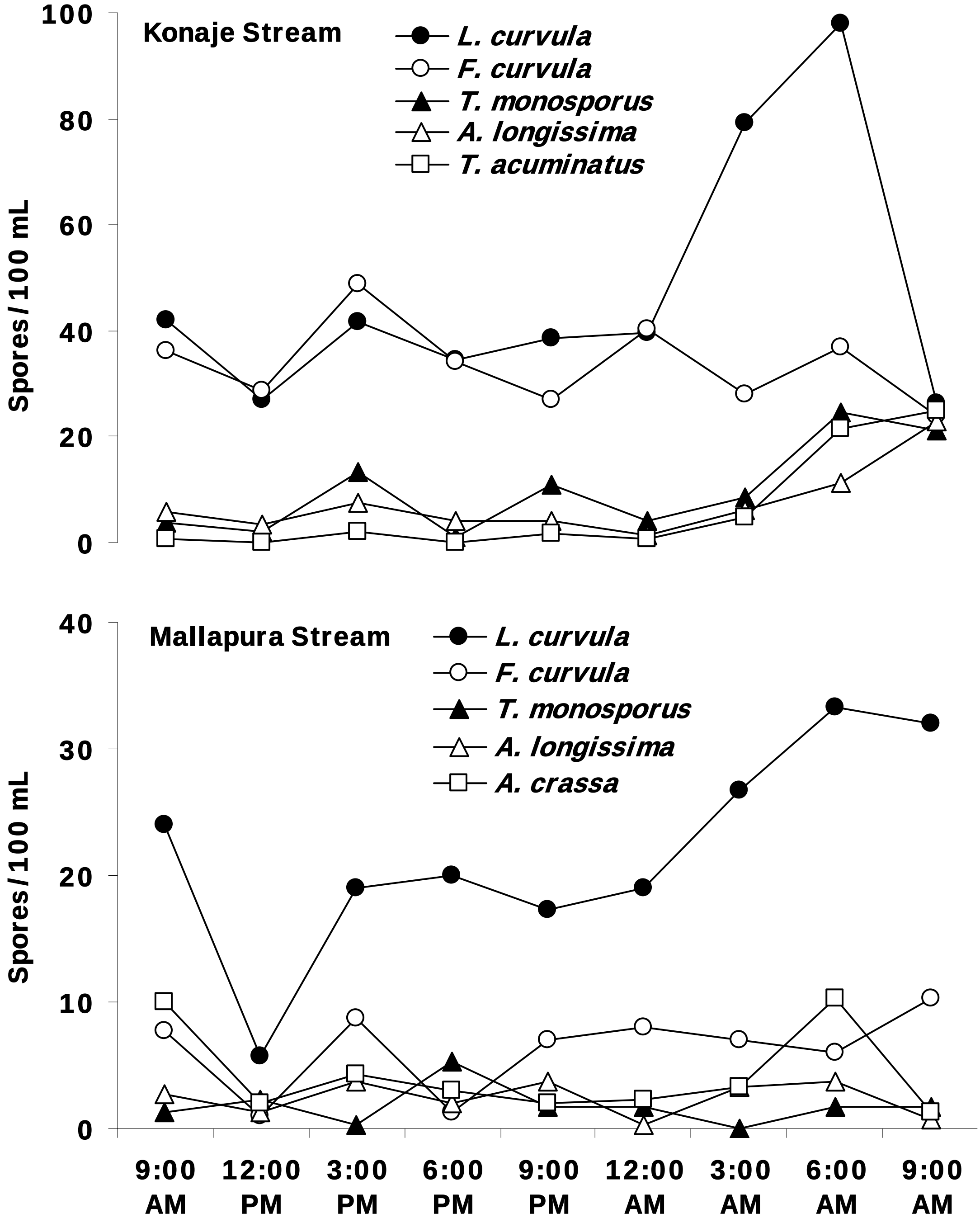

Fig. 3. – Diurnal fluctuation in spore output of five dominant freshwater hyphomycetes in the Konaje and Mallapura streams (n = 5, mean).

two regions, Thomas et al. (1991) predicted that constant supply of substrata adds spores to water faster than they are lost. Thomas et al. (1992) in a three day consecutive study demonstrated an increase in spore concentration from morning to evening of each day (24–38%) followed by decrease each night (17–30%). Spore release pattern of the 10 most abundant species of freshwater hyphomycetes were also similar to that of total spores. However, a field-based experiment by Thomas et al. (1992) could not attribute the pattern of diurnal spore fluctuation to an alternating light regime. They suggested two possibilities for the diurnal changes in spore concentration of Lees Creek: minor fluctuation in water temperature (1.5ºC) and the effect of leaf-shredding macroinvertebrates. Studies have been conducted to understand the influence of temperature on sporulation of freshwater hyphomycetes in pure cultures, which demonstrated that the optimum sporulation temperature was lower than optimum growth temperature in several species (e.g. *Alatospora acuminata, Tetracladium marchalianum, Lunulospora curvula* and *Varicosporium elodeae*) (Koake and Duncan 1974, Gönczöl 1975, Webster et al. 1976, Suberkropp 1984). The leaf-shredding macroinvertebrates (which are active during night) have the ability to selectively feed on leaves colonized by freshwater hyphomycetes (Bärlocher & Kendrick 1981) and thus deplete the fungal biomass especially during night.

Although our study showed a clear evidence of diurnal periodicity in spores of freshwater hyphomycetes, it is contrasting compared to diurnal studies in temperate streams of Australia (Thomas et al. 1991, 1992). Significantly elevated temperature during the day in our study might have resulted in vegetative growth with low spore output by freshwater hyphomycetes followed by higher sporulation due to lowered temperature and elevated oxygen during the night. In addition, the mycelia of fungi in both streams were not lost to leaf-shredding invertebrates as these streams were devoid of them. The pattern of spore fluctuation of the dominant species *Lunulospora curvula* coincided with total spores (see Fig. 3). The pattern of diurnal fluctuation of spores of 10 most abundant species of freshwater hyphomycetes in Lees Creek of Australia was similar to that of total spore fluctuation (Thomas et al. 1992). However, besides *Lunulospora curvula* the rest of the dominant species in our study (*Anguillospora longissima*, *Flagellospora curvula, Triscelophorus monosporus* and *Anguillospora crassa* or *Triscelophorus acuminatus*) did not clearly follow the fluctuation pattern of total spores and warrants further study. In Australian streams, Thomas et al. (1992) did not find a relationship of diurnal spore fluctuation with that of light. In our study, it is likely the light might have induced vegetative growth rather than sporulation during the day due to elevation of water temperature and decreased oxygen followed by spore output during night with lowered temperature and increased dissolved oxygen. Rajashekhar & Kaveriappa (2000) demonstrated spore production of leaf litter colonized freshwater hyphomycetes was higher in continuous light than diurnal photoperiod (e.g. *Angulillospora longissima, Tumularia aquatica, Dendrosporium lobatum, Flagellospora curvula, Lunulospora curvula, Triscelophorus monosporus* and *Wiesneriomyces laurinus*). However, in these light regimes, sporulation of some species was not altered (e.g. *Campylospora chaetocladia, Flabellospora verticillata* and *Speiropsis pedatospora*), while in some species it decreased under continuous light (e.g., *Flagellospora penicillioides, F. saccata* and *Lunulospora cymbiformis*). Interestingly, continuous darkness induced more sporulation than diurnal photoperiod in *Tumularia aquatica* and *Dendrosporium lobatum*.

So far, about 20 species are known from the Konaje stream (Sridhar et al. 1992, Karamchand 2008). In the present study, up to 19 species were recovered based on diurnal spore output and indicates the involvement of most of the species in leaf litter processing. The diversity in Konaje stream was higher during the night than day, but it was reverse in the Mallapura stream (see Table 4) probably due to factors such as substrate/water qualities and agricultural/human interference. In these streams, besides typical spores of freshwater hyphomycetes, other spores such as *Robillarda* sp., *Tetraploa aristata* and *Tetraploa* sp. were also seen (which were not considered for evaluation) indicating their involvement in leaf litter processing.

The pH in both streams decreased during night as compared to day (which was significant in the Mallapura stream) and this might be responsible for increased trend of species richness during night in both streams (see Fig. 1). However, total species were lower during the night in the Mallapura stream as compared to the day (see Fig. 2). The species richness was negatively correlated with pH in both temperate and tropical streams (Wood-Eggenschwiler & Bärlocher 1983, Bärlocher 1987, Raviraja et al. 1998b). Slow or negligible decrease in species richness in circumneutral waters (5.7−7.2) with a rapid decline in alkaline waters (> 7.2) have been demonstrated by Bärlocher (1987) in Canadian and European streams. This has been supported by Raviraja et al. (1998b) based on negative correlation between species richness vs. pH in tropical streams of the Western Ghats.

Assessment of drift spores of freshwater hyphomycetes will serve as an easy and quick method to understand the role of fungi in structural and functional attributes of streams. The current study revealed different pattern of diurnal fluctuation of species and spores of freshwater hyphomycetes as compared to temperate studies. Further investigation needs to address: i) consistency of patterns of diurnal spore output in other tropical streams; ii) the patterns of diurnal spore output during summer and monsoon seasons (due to variation in photoperiod and leaf litter input); iii) the impact of leaf-shredding invertebrates and human interference (loading organic matter /pollutants) on the diurnal periodicity of spores of freshwater hyphomycetes.

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References

Aimer RD, Segedin BP 1985 – Fluctuation in spore number of aquatic hyphomycetes in a New Zealand stream. Botanical Journal of the Linnean Society 91, 61–66.

APHA 1995 – Standard Methods in Examination of Water and Waste Water. American Public Health Association, USA.

Bärlocher F 1987 – Aquatic hyphomycete spora in 10 streams of New Brunswick and Nova Scotia. Canadian Journal of Botany 65, 76–79.

Bärlocher F 1992 – Community organization. In: The Ecology of Aquatic Hyphomycetes (ed F Bärlocher). Springer, Berlin and New York, 38–76.

Bärlocher F 2009 – Reproduction and dispersal of aquatic hyphomycetes. Mycoscience 50, 3–8.

Bärlocher F, Kendrick B 1981 – Role of aquatic hyphomycetes in the trophic structure of streams. In: The Fungal Community (ed DT Wicklow, GC Carroll). Marcel Dekker, New York, 743–760.

Bärlocher F, Rosset J 1981 – Aquatic hyphomycete spora in two Black Forest and two Swiss Jura streams. Transactions of the British Mycological Society 76, 479–483.

Chandrashekar KR, Sridhar KR, Kaveriappa KM 1990 – Periodicity of water-borne hyphomycetes in two streams of Western Ghat forests (India). Acta Hydrochimica et Hydrobiologica 18, 187–204.

Chauvet E 1991 – Aquatic hyphomycete distribution in South-Western France. Journal of Biogeography 18, 699–706.

Chauvet E, Suberkropp K 1998 – Temperature and sporulation of aquatic hyphomycetes. Applied and Environmental Microbiology 64, 1522–1525.

Fabre E 1997 – Changes in concentration of aquatic hyphomycete conidia in water passing through a concrete pipe. Mycological Research 101, 908–910.

Fabre E 1998 – Aquatic hyphomycetes in three rivers of southwestern France: 1 Spatial and temporal changes in conidial concentration, species richness and community diversity. Canadian Journal of Botany 76, 99–106.

Findlay SEG, Arsuffi TL 1989 – Microbial growth and detritus transformations during decomposition of leaf litter in a stream. Freshwater Biology 21, 261–269.

Gessner MO 1997 – Fungal biomass, production and sporulation associated with particulate organic matter in streams. Limnetica 13, 33–44.

Gessner MO, Bärlocher F, Chauvet E 2003 – Quantitative and qualitative analysis of aquatic hyphomycetes in streams. In: Freshwater Mycology (ed CKM Tsui, KD Hyde). Fungal Diversity Series # 10, Hong Kong, 127–157.

Gönczöl J 1975 – Ecological observations on the aquatic hyphomycetes of Hungary I. Acta Botanica Hungarica 21, 243–264.

Gönczöl J, Révay A 1999 – Studies on the aquatic hyphomycetes of the Morgó stream, Hungary II. Seasonal periodicity of conidial populations. Archiv für Hydrobiologie 144, 495–508.

Gönczöl J, Révay A, Csontos P 2001 – Effect of sample size on the detection of species and conidial numbers of aquatic hyphomycetes collected by membrane filtration. Archiv für Hydrobiologie 150, 677–691.

Ingold CT 1942 – Aquatic hyphomycetes of decaying alder leaves. Transactions of the British Mycological Society 25, 339–417.

Iqbal SH, Webster J 1973 – Aquatic hyphomycete spora of the River Exe and its tributaries. Transactions of the British Mycological Society 61, 331–346.

Karamchand KS 2008 – Studies on Freshwater Filamentous Fungi of Western Ghats and West Coast of India. PhD Thesis, Mangalore University, India.

Koake RE, Duncan IW 1974 – Temperature effects on growth, sporulation and germination of some aquatic hyphomycetes. Canadian Journal of Botany 52, 1387–1391.

Lindsey BI, Glover BJ 1976 – Ecological studies of spores of aquatic hyphomycetes in the Cringle Brook, Lincs. Hydrobiologia 51, 201–208.

Magurran AE 1988 – Ecological Diversity and its Measurement. Princeton University Press, New Jersey.

Maharning AR, Bärlocher F 1996 – Growth and reproduction in aquatic hyphomycetes. Mycologia 88, 80–88.

Müller-Haeckel A, Marvanová L 1979 – Periodicity of aquatic hyphomycetes in the subarctic. Transactions of the British Mycological Society 73, 109–116.

Pielou FD 1975 – Ecological Diversity. Wiley InterScience, New York.

Rajashekhar M, Kaveriappa KM 1993 – Ecological observations on water-borne hyphomycetes of Cauvery River and its tributaries in India. Archiv für Hydrobiologie 126, 487–497.

Rajashekhar M, Kaveriappa KM 2000 – Effects of temperature and light on growth and sporulation of aquatic hyphomycetes. Hydrobiologia 441, 149–153.

Raviraja NS, Sridhar KR, Bärlocher F 1998a – Breakdown of *Ficus* and *Eucalyptus* leaves in an organically polluted river in India: fungal diversity and ecological functions. Freshwater Biology 39, 537–545.

Raviraja NS, Sridhar KR, Bärlocher F 1998b – Fungal species richness in Western Ghat streams (Southern India); is it related to pH, temperature or altitude? Fungal Diversity 1, 179–191.

Shearer CA, Lane LC 1983 – Comparison of three techniques for the study of aquatic hyphomycete communities. Mycologia 75, 498–508.

Shearer CA, Webster J 1985 – Aquatic hyphomycete community structure in the River Teign II. Temporal distribution patterns. Transactions of the British Mycological Society 84, 503–507.

Sridhar KR, Kaveriappa KM 1984 – Seasonal occurrence fungi in Konaje stream (Mangalore), India. Hydrobiologia 119, 101–105.

Sridhar KR, Kaveriappa KM 1989 – Observations on aquatic hyphomycetes of the Western Ghat streams, India. Nova Hedwigia 49, 455–467.

Sridhar KR, Chandrashekar KR, Kaveriappa KM 1992 – Research on the Indian subcontinent. In: The Ecology of Aquatic Hyphomycetes (Ed F Bärlocher). Springer-Verlag, Heidelberg, 182–211.

Sridhar KR, Bärlocher F 2000 – Initial colonization, nutrient supply and fungal activity on leaves decaying in streams. Applied and Environmental Microbiology 66, 1114–1119.

Suberkropp K 1984 – Effect of temperature on seasonal occurrence of aquatic hyphomycetes. Transactions of the British Mycological Society 82, 53–62.

Suberkropp K 1991 – Relationships between growth and sporulation of aquatic hyphomycetes on decomposing leaf

litter. Mycological Research 98, 843–850.
Suberkropp K 1995 – The influence of nutrients on fungal growth, productivity, and sporulation during leaf breakdown in streams. Canadian Journal of Botany 73, S1361–S1369.
Thomas K, Chilvers GA, Norris RH 1989 – Seasonal occurrence of conidia of aquatic hyphomycetes (fungi) in Lees Creek, Australian capital territory. Australian Journal of Marine and Freshwater Research 40, 11–23.
Thomas K, Chilvers GA, Norris RH 1991 – Changes in concentration of aquatic hyphomycete spores in Lees Creek, ACT, Australia. Mycological Research 93, 178–183.
Thomas K, Chilvers GA, Norris RH 1992 – Diurnal variation in aquatic hyphomycete spore concentration in an Australian stream. Mycological Research 96, 89–92.
Webster J, Moran ST, Davey RA 1976. Growth and sporulation of *Tricladium chaetocladium* and *Lunulospora curvula* in relation to temperature. Transactions of the British Mycological Society 67, 491–495.
Wood-Eggenschwiler S, Bärlocher F 1983 – Aquatic hyphomycetes in sixteen streams in France, Germany and Switzerland. Transactions of the British Mycological Society 81, 371–379.