Diversity of water-borne fungi in stemflow and throughfall of tree canopies in India

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Stemflow and throughfall of 14 non-riparian tree species of the southwest coast of India represented conidia of 63 water-borne hyphomycetes (conidial shape: three conventional, six sigmoid, six helicosporus, 48 multiradiate) consisting of 19 species as new record to the tree canopies. *Anguillospora crassa, A. longissima, Flagellospora curvula, Trinacrium subtile, Triscelophorus acuminatus, Trisulcosporium acerinum*, and *Ypsilina graminea* were dominant. The species richness of water-borne hyphomycetes was highest in stemflow of *Ficus benghalensis* and in throughfall of *Artocarpus integrifolius*. The conidial output was highest in stemflow of *Tectona grandis* and in throughfall of *Ficus religiosa*. The average conidial output per species of water-borne hyphomycetes was highest in stemflow as well as throughfall of *Tectona grandis*. The Simpson and Shannon diversities were highest in stemflow and throughfall of *Ficus benghalensis*. The Jaccard's percent similarity of water-borne hyphomycetes among the tree species studied was ranged between 19 % and 56 %.

Keywords: anamorphic ascomycetes, non-riparian trees, biodiversity

Forest canopies provide several habitats for flora, fauna and microbes as they trap considerable amounts of organic matter (e.g., leaf litter, twigs, inflorescences). A broad group of fungi has been represented in tree canopies including endophytic, pathogenic, phylloplane, and lignicolous fungi (Lodge & Cantrell 1995). In addition, typical aquatic/water-borne and aero-aquatic fungi are also represented in forest canopies (Gönczöl & Révay 2006, Sridhar *et al*. 2006). Water-borne hyphomycetes are usually abundant in submerged dead leaf litter in streams and constitute a vital link in stream food webs (Ingold 1942, Bärlocher 1992). Besides streams and canopies, they are also known from a variety of terrestrial habitats such as soil, leaf litter, and roots (Sridhar & Bärlocher 1993).

Ingold (1942, 1953) predicted three selective pressures responsible for conidial shapes (sigmoid and multiradiate) of aquatic hyphomyc-

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etes: (i) delayed sedimentation for dispersal, (ii) settlement on a suitable substrate and (iii) prevention from ingestion by invertebrates. Subsequently, Ingold (1975) put forth the concept of convergent evolution in aquatic hyphomycetes based on their two basic spore shapes. Conventional studies on anamorph-teleomorph connections revealed that aquatic hyphomycetes are linked with several terrestrial ascomycetes growing in decaying tree branches (Webster & Descals 1979, Webster 1992, Sivichai & Jones 2003). Morphological evidences of helicosporus fungi (also called aero-aquatic fungi, which possess brown asexual spores with a minimum twist of 180°) indicated their affiliations with multiple families belonging to different classes of ascomycetes (Goos 1987, Zhao *et al*. 2007).

'Stemflow' is defined as water from mist or rain flowing to the ground along the outside of stems, while 'throughfall' as mist or rain dripping from foliage to the ground (Moffett 2000). Most studies on water-borne conidial fungi in tree canopies (e.g., stemflow, throughfall, tree holes) confined to temperate regions: Canada (Bandoni 1981), Hungary (Gönczöl & Révay 2006), Japan (Ando & Tubaki 1984) and Poland (Czeczuga & Orłowska 1997). Recently, a few studies addressed the assemblage and diversity of water-borne fungi in epiphytic tree fern (Sridhar *et al*. 2006) and tree holes (Karamchand & Sridhar 2008) from the tropical region of Southwest India. Extensive rainfall during southwest monsoon in southern India (approx. 350-650 cm/annum) results in continuous wet tree canopies in the Western Ghats and west coast between June and September. Such aquatic or semi-aquatic conditions likely support the growth, sporulation and dissemination of water-borne fungi in different habitats. The current study aims at inventorying the assemblage and diversity of water-borne fungi in stemflow and throughfall of non-riparian trees of the south west coast of India during southwest monsoon season.

Materials and Methods

The sampling site, Mangalore University Campus (12° 48' 50.79" N, 74° 55' 38.28" E; altitude: 110 m a.s.l.) located about 20 km away from the Mangalore City on the southwest coast of India was selected for the investigation. One each of 14 non-riparian tree species distributed in an area of 200 m^2 on the campus and about one km away from the nearest stream source was selected for the study. The trees selected were solitary and devoid of interference of canopies of other tree species. During July 2007 (southwest monsoon period), stemflow and throughfall of selected trees were sampled. Shortly after the beginning of heavy rain (ca. 30 min), about 200 mL of water draining through the main stem of each tree species was collected in sterile polythene bags and stored in sterile glass bottles. A clean polythene sheet (2 m^2) was spread below the canopy of each tree at about 1 m above the ground and 3 m away from the tree base and approximately 200 mL of water dripping through the canopy was sampled and transferred to wide mouthed sterile glass bottles. During heavy rainy periods,

Temperature, pH and conductivity of aliquots of stemflow and throughfall of each tree were assessed on the spot using a water analyzer (Systronics, Water Analyzer 371, Gujarat, India). Water samples (50 mL each) were fixed at the sampling site to estimate dissolved oxygen using Winkler's method (APHA 1995). Within 30 min of sampling, 25 mL each of stemflow and throughfall were separately filtered through Millipore filters (5 µm; diam., 47 mm) to assess the conidial assemblage of water-borne hyphomycetes. The filters were stained with 0.1 % cotton blue in lactophenol. Later, each filter was cut into half, mounted on a microscope slide with a few drops of lactic acid, screened for the presence of conidia of water-borne hyphomycetes. Identification of conidia was based on spore descriptions using relevant monographs (e.g., Ingold, 1975b; Marvanová 1997, Gulis *et al.* 2007). Conidia/spores were counted using a Nikon microscope (YS100; Nikon Corporation, Tokyo, Japan) (magnification, 400 X and/or 1000 X). One-eighth or one-quarter area of filter was scanned if conidia were numerous, while the whole filter was scanned if they were sparse. Quantitative and qualitative estimates of conidia were made out of 10 mL samples.

The mean number of conidia per tree species per 10 mL stemflow or throughfall (N) was estimated:

$$N = \frac{\sum_C}{\sum_S}$$

($\sum_C$ = Total number of conidia per 10 mL in all tree species; $\sum_S$ = Total number of tree species)

The mean number of conidia per fungal species per milliliter stemflow or throughfall (N_S) was estimated:

$$N_S = \frac{\sum_{CS}}{\sum_{FS}}$$

($\sum_{CS}$ = Total number of conidia per 1 mL in a specific tree species; $\sum_{FS}$ = Total number of fungal species recorded from a specific tree species)

As considerable number of diverse fungi was found in stemflow as well as throughfall; their diversity was estimated using the Simpson index (D′) and Shannon index (H′) (Magurran 1988):

$$D' = \frac{1}{\sum p_i^2} \qquad \mathrm{H}' = -\sum (p_i \times \ln p_i)$$

(Where p_i is the proportion by which the ith species contributes to the total number of individuals)

Paired t-test was used to assess the difference in overall conidial population between stemflow and throughfall (StatSoft Inc. 1995).

Jaccard's index of similarity (J) of fungi was calculated pair-wise among the tree species based on the presence or absence of each fungal species in stemflow or throughfall (Kenkel & Booth 1992):

$$J(\%) = \frac{c}{(a + b + c)} \times 100$$

(Where c is the number of fungal species occurring in both tree species, a is the number of species unique to the first tree species, and b is the number of species unique to the second tree species).

Results

Table 1 gives the details of 14 non-riparian tree species surveyed for the assemblage of water-borne fungi in their stemflow and throughfall. The pH and conductivity of stemflow and throughfall ranged between 6.02 and 7.58, 10.1 µS/cm and 72.9 µS/cm, respectively. The temperature ranged between 23.5 °C and 26 °C.

Altogether, 63 species of water-borne fungi were identified from the stemflow and throughfall of 14 tree species (Table 2). The number

Tab. 1. – Non-riparian trees screened for water-borne conidial fungi, pH, and conductivity of stemflow and throughfall (in parenthesis).

Tree species	Code	Sampling date	pH	Conductivity (µS/cm)
Acacia auriculiformis A. Cunn. ex Benth	Aa	Jul 31, 2007	6.10 (7.27)	15.7 (14.1)
Alstonia scholaris (L.) R. Br.	As	Jul 27, 2007	6.55 (7.04)	19.4 (32.1)
Artocarpus integrifolius auct. non L. f.	Ai	Jul 23, 2007	7.53 (7.58)	24.8 (42.9)
Carallia brachiata (Lour.) Merr.	Cb	Jul 28, 2007	6.22 (7.02)	21.7 (24.7)
Careya arborea Roxb.	Ca	Jul 25, 2007	7.34 (7.39)	17.6 (57.4)
Eucalyptus tereticornis Smith.	Et	Jul 25, 2007	6.96 (7.16)	38.9 (40.2)
Ficus benghalensis L.	Fb	Jul 28, 2007	7.07 (7.57)	16.4 (19.2)
Ficus religiosa L.	Fr	Jul 17, 2007	7.42 (7.34)	39.3 (72.9)
Mangifera indica L.	Mi	Jul 16, 2007	6.19 (7.03)	11.3 (36.7)
Odina wodier Roxb.	Ow	Jul 16, 2007	6.97 (7.43)	10.1 (40.1)
Pongamia glabra Vent.	Pg	Jul 16, 2007	6.53 (7.51)	16.2 (48.9)
Syzygium cumini (L.) Skeels	Sc	Jul 28, 2007	7.27 (7.07)	24.4 (15.9)
Tectona grandis L. f.	Tg	Jul 19, 2007	6.02 (7.29)	23.6 (30.7)
Terminalia paniculata Roth.	Tp	Jul 28, 2007	7.26 (7.13)	23.0 (38.1)

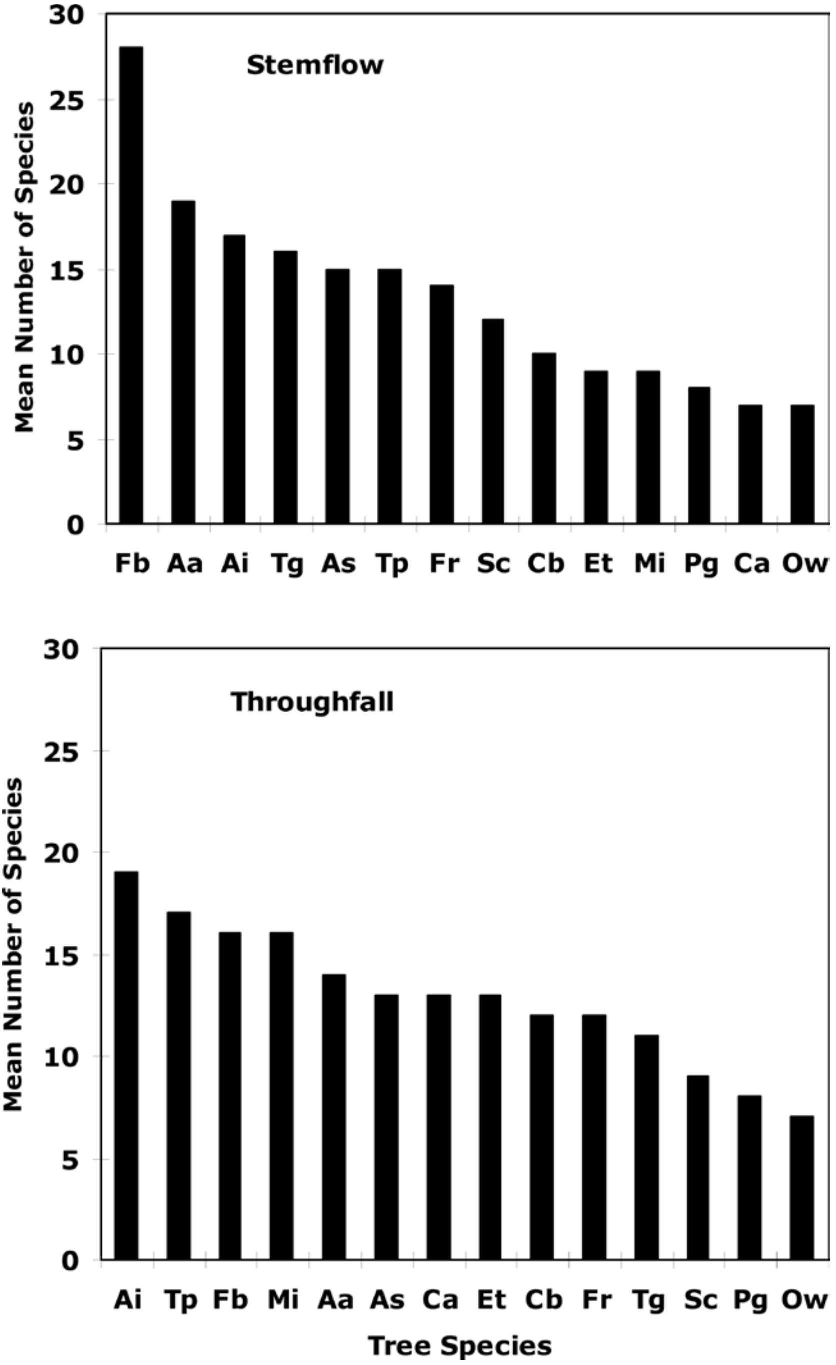

Fig. 1. – Mean number of fungal species in stemflow and throughfall of 14 non-riparian tree species of Konaje region (see Table 1 for details of tree species)

Tab. 2. – Conidia of water-borne hyphomycetes (conidia/10 mL) recovered from stem flow and through fall (numbers in parenthesis) of 14 non-riparian tree species of southwest coast of India. (Tree species: Aa, *Acacia auriculiformis*; As, *Alstonia scholaris*; Ai, *Artocarpus integrifolius*; Cb, *Carallia brachiata*; Ca, *Careya arborea*; Et, *Eucalyptus tereticornis*; Fb, *Ficus benghalensis*; Fr, *Ficus religiosa*; Mi, *Mangifera indica*; Ow, *Odina wodier*; Pg, *Pongamia glabra*; Sc, *Syzygium cumini*; Tg, *Tectona grandis*; Tp, *Terminalia paniculata*) (MCT, mean number of conidia per tree species in 10 mL) (* New report from tree canopies.)

Fungal taxa	Tree species														MCT
	Aa	**As**	**Ai**	**Cb**	**Ca**	**Et**	**Fb**	**Fr**	**Mi**	**Ow**	**Pg**	**Sc**	**Tg**	**Tp**	
Alatospora acuminata Ingold	5			3	(2)	2	5 (3)	3	(6)				6	2 (3)	1.9 (1.0)
Anguillospora crassa Ingold	8 (2)	16 (5)	11	10 (26)	5 (5)	6 (5)	11 (2)	11 (16)	26 (6)	6 (5)	21 (11)	10 (3)	54 (22)	8 (26)	14.5 (9.6)
A. longissima (Sacc. & Sydow) Ingold	70 (61)	88 (14)	138 (61)	88 (43)	14 (24)	26 (19)	46 (11)	86 (160)	3 (64)	48 (43)	24 (77)	27 (24)	26 (106)	26 (74)	50.7 (55.8)
Arborispora dolichovirga Ando *	2													5	0.5
A. paupera Marvanová and Bärlocher *													22		1.6
Arborispora sp.									2						0.1
Campylospora chaetocladia Ranzoni							2								0.1
C. parvula Kuzuha *							2								0.1
Clavariopsis aquatica de Wild.									(2)						(0.1)
Clavatospora tentacula (Umphlett) Nilsson *	2						3								0.4
Curicispora ponapensis Matsushima					(2)	(13)	(2)		2 (2)			2			0.3 (1.4)
Cylindrocarpon sp.		10 (5)													0.7 (0.4)
Dendrospora sp. *		10 (2)		(2)											0.7 (0.3)
Dicranidion gracilis Matshshima *											3	2 (11)			0.4 (0.8)
Dwayaangam cornuta Descals	(2)							3 (16)							0.2 (0.4)

D. dichotoma Nawawi							(2)	2							0.1 (0.1)
Dwayaangam sp.	2	2	(2)			(2)		2							0.4 (0.3)
Flabellospora crassa Alasoadura						(2)	(2)								0.1
F. multiradiata Nawawi							2						(3)		(0.3)
F. verticillata Alasoadura	3 (3)	3 (2)				2 (3)							10 (3)		1.3 (0.8)
Flagellospora curvula Ingold	24 (8)	11 (5)	53 (11)	24 (10)	40 (14)	77 (45)	16 (8)	27 (70)	3 (8)	6 (5)	6 (3)	38 (24)	166 (22)	5 (11)	35.4 (17.4)
F. penicillioides Ingold			5 (2)				2								0.5 (0.1)
Helicella stellata (Ingold & Cox) Marvanová *		(2)					5			(3)	5			(3)	0.7 (0.6)
Helicodendron sp.									(2)						(0.1)
Helicoma ambiens Morgan *													22	(2)	1.6 (0.1)
H. colligatus Moore *		(2)						(3)					10		0.7 (0.4)
Helicomyces roseus Link *			3 (11)				3						3		0.6 (0.8)
H. scandens Morgan *									(2)			(2)			(0.3)
Helicosporium sp.						2 (3)	2						6	1 (3)	0.8 (0.4)
Isthmotricladia laeensis Matushima			2 (5)			(5)		2	(3)						0.3 (0.9)
Lateriramulosa quadriradiata Miura & Okano	2		(2)	(2)			2		3					2 (2)	0.6 (0.4)
L. uni-inflata Matsushima		(5)		2											0.1 (0.4)
Lemonniera aquatica de Wild.							2						6 (10)		0.6 (0.7)

Table 2. – continued

Fungal taxa	Tree species														MCT
	Aa	**As**	**Ai**	**Cb**	**Ca**	**Et**	**Fb**	**Fr**	**Mi**	**Ow**	**Pg**	**Sc**	**Tg**	**Tp**	
L. cornuta Ranzoni			(2)								3				0.2 (0.1)
L. terrestris Tubaki		2													0.1
Lunulospora curvula Ingold	2 (2)	2 (5)	5 (3)		14 (11)		24 (11)		(2)		(2)			5 (2)	3.7 (2.7)
Mycocentrospora acerina Deighton *	8 (3)										2 (2)			2 (5)	0.9 (0.7)
Phalangispora constricta Nawawi & Webster							2								0.1
Retiarius bovicornutus Olivier		2					3 (2)								0.4 (0.1)
Speiropsis pedatospora Tubaki							5							2 (6)	0.5 (0.4)
Synnematospora constricta Sridhar & Kavariappa*	2					(2)									0.1 (0.1)
Tetraploa aristata Berk. & Br.							2								0.1
Titaea clarkeae Ellis & Everh.			2 (2)				3 (5)	(3)				2 (2)	3		0.7 (0.9)
Titaea sp. *				(3)					3						0.2 (0.2)
Titaeella canophila Arnaud ex Ando & Tubaki *								(3)							(0.2)
Tricladiomyces malaysianus (Nawawi) Nawawi *			5 (45)		(3)	(3)	2								0.5 (3.6)
Tricladium splendens Ingold						2	(3)		(6)						0.1 (0.6)
Trinacrium robustum Tzean & Chen							2	(10)				2			0.3 (0.7)

T. subtile Riess	3 (5)	5 (2)	5 (21)	7 (8)	(7)	7 (13)	5 (10)	14 (10)	(6)	(3)	2 (2)	2 (2)	93 (19)	2 (7)	10.4 (7.1)
Trinacrium sp. *			2 (5)									2			0.3 (0.4)
Tripospermum prolongatum Sinclair & Morgan-Jones *			2 (26)					5 (58)	4 (2)						0.8 (6.1)
T. myrti (Lind.) Hughes							(5)								(0.4)
Triscelophorus acuminatus Nawawi	24 (42)	2	2 (5)	5 (2)	2 (2)	2		3 (6)	(3)	2	(2)	5 (8)	16 (26)	2 (6)	4.6 (7.3)
T. konajensis Sridhar & Kaveriappa	22 (8)	(3)	2		(2)	(3)	2 (3)	13	(2)	3 (3)		(3)	(6)	2 (3)	3.1 (2.6)
T. monosporus Ingold	10 (6)	(2)	2 (2)	(2)	2		2				(2)				1.1 (1.0)
Trisulcosporium acerinum Hudson & Sutton	14 (8)		2 (11)	2 (2)	(3)		(2)		(5)	3 (2)		(3)	(51)		1.5 (6.2)
Tumularia tuberculata (Gönczol) Descals & Marvanová		2											3		0.4
Vanrija aquatica (Jones & Slooff) Moore *	(2)						(2)							(2)	(0.4)
Varicosporium elodeae Kegel	3 (3)						5					2			0.7 (0.2)
Ypsilina graminea (Ingold, Dann & McDougall) Descals, Webster & Marvanová		10	10 (5)	2 (5)	(5)		5			27		21	80 (70)	2 (7)	11.2 (6.5)
Unidentified 1 (tetraradiate, curved)	2	2	5 (5)	5 (2)	(2)		5	3 (6)	2					2 (3)	1.9 (1.3)
Unidentified 2 (tetraradiate H-shaped)					3										0.2
Unidentified 3 (sickle-like)								8							0.6
Total taxa	**19 (14)**	**15 (13)**	**17 (18)**	**10 (12)**	**7 (13)**	**9 (13)**	**28 (16)**	**14 (12)**	**9 (16)**	**7 (7)**	**8 (8)**	**12 (9)**	**16 (11)**	**15 (17)**	
Total number of conidia per 10 mL	**208 (155)**	**167 (54)**	**256 (221)**	**148 (107)**	**80 (82)**	**126 (118)**	**170 (73)**	**182 (361)**	**48 (121)**	**95 (64)**	**66 (101)**	**115 (82)**	**526 (338)**	**68 (165)**	

of species were highest in stemflow of *Ficus benghalensis* (28 species) and throughfall of *Artocarpus integrifolius* (19 species), while it was lowest in stemflow of *Careya arborea*, *Odina wodier,* and in throughfall of *Odina wodier* (7 species) (Fig. 1). *Anguillospora crassa, A. longissima, Flagellospora curvula*, *Trinacrium subtile, Triscelophorus acuminatus, Trisulcosporium acerinum* and *Ypsilina graminea* dominated in stemflow as well as throughfall (Table 2).

The conidial output was highest in stemflow of *Tectona grandis* (526/10 mL) and in throughfall of *Ficus religiosa* (361/10 mL), while it was lowest in stemflow of *Mangifera indica* (48/10 mL) and throughfall of *Alstonia scholaris* (54/10 mL) (Table 2, Fig. 2). The mean number of conidia per species was highest in stemflow as well as throughfall of *Tectona grandis* (3.1-3.3/mL) (Fig. 2). The conidial output in stemflow and throughfall was not significantly different ($P = 0.2544$).

The Simpson and Shannon diversities for stemflow as well as throughfall of *Ficus benghalensis* revealed the highest values, while the lowest were calculated for *Eucalyptus tereticornis* (stemflow) and *Pongamia glabra* (throughfall) (Fig. 3). Out of 91 pair-wise comparisons by Jaccard's similarity index, only five pairs showed ≥ 50 % similarity (range: 50–56 %), and the range of 19-48 % in the rest of pairs depicts a greater dissimilarity of water-borne fungi among the tree species (Table 3).

Tab. 3. – Jaccard's percent similarity of fungal species found in tree canopy drained water (stemflow and throughfall) of 14 non-riparian tree species of the west coast of India.

	Tree species												
	As	Ai	Cb	Ca	Et	Fb	Fr	Mi	Ow	Pg	Sc	Tg	Tp
Aa	37	43	37	48	40	38	40	41	36	33	31	35	52
	As	31	36	43	27	23	30	25	42	33	29	30	37
		Ai	39	50	35	32	38	41	36	32	36	30	37
			Cb	56	25	24	29	36	47	32	33	35	39
				Ca	41	36	32	48	50	35	41	36	45
					Et	28	38	38	28	23	28	38	31
						Fb	24	26	22	19	29	32	36
							Fr	36	29	21	32	31	29
								Mi	32	24	36	27	33
									Ow	43	53	40	42
										Pg	30	22	37
											Sc	35	27
												Tg	38

Aa, *Acacia auriculiformis*; As, *Alstonia scholaris*; Ai, *Artocarpus integrifolius*; Cb, *Carallia brachiata*; Ca, *Careya arborea*; Et, *Eucalyptus tereticornis*; Fb, *Ficus benghalensis*; Fr, *Ficus religiosa*; Mi, *Mangifera indica*; Ow, *Odina wodier*; Pg, *Pongamia glabra*; Sc, *Syzygium cumini*; Tg, *Tectona grandis*; Tp, *Terminalia paniculata*).

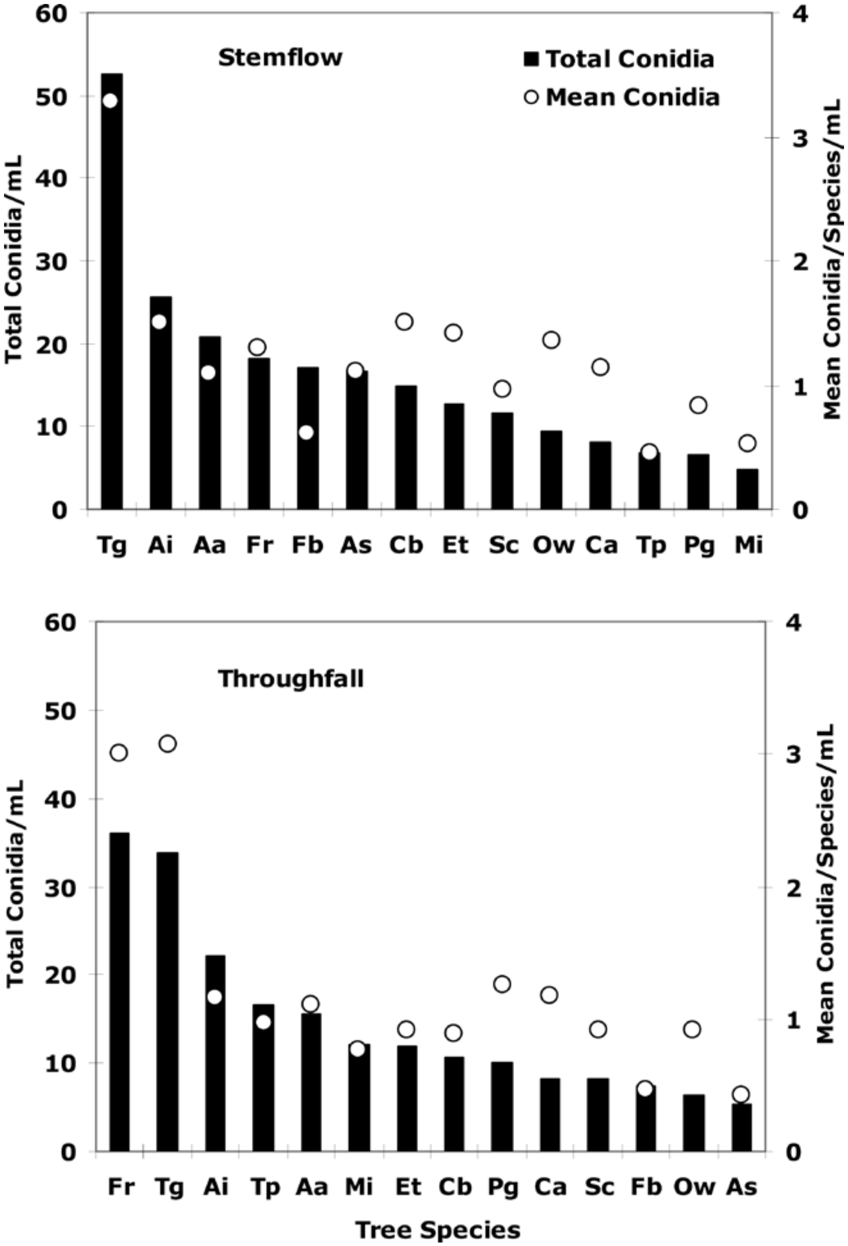

Fig. 2. – Conidia per mL and mean conidia per species per mL of stemflow and throughfall of 14 non-riparian tree species of Konaje region (see Table 1 for details of tree species)

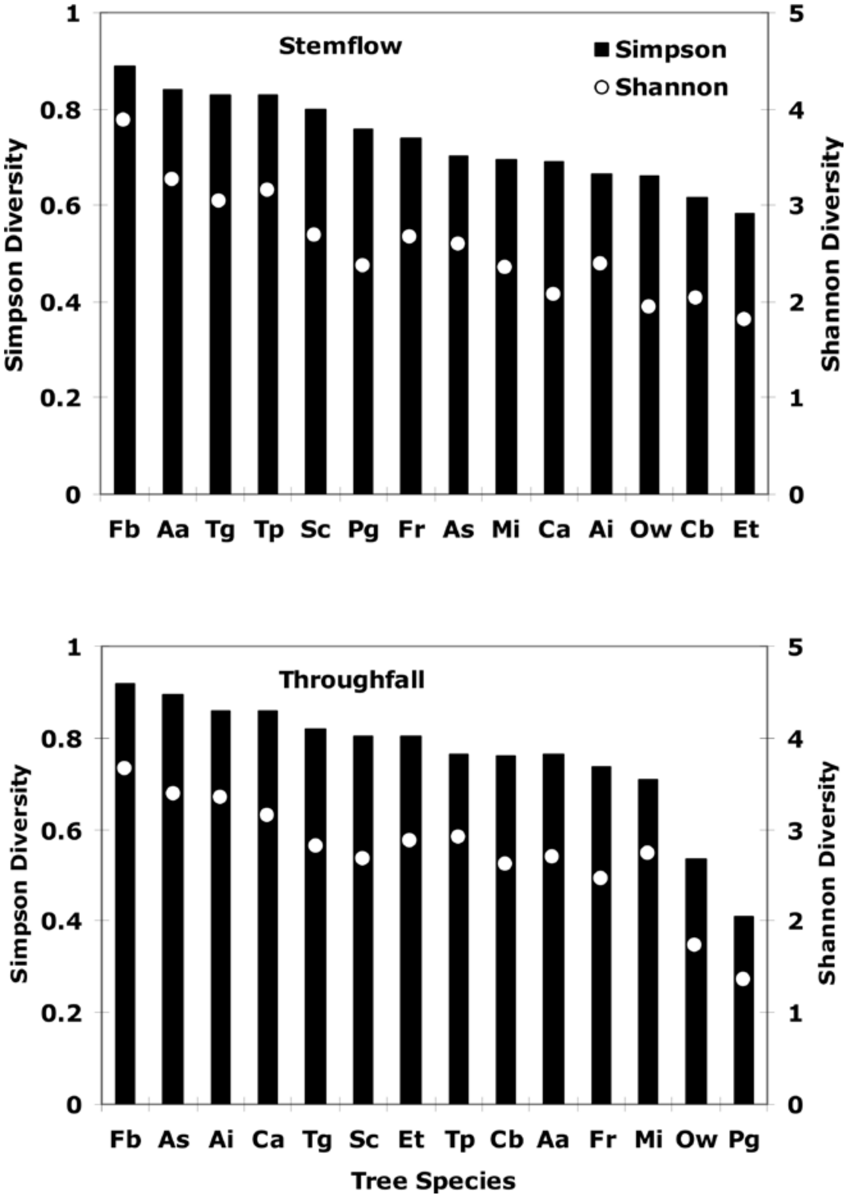

Fig. 3. – Simpson and Shannon diversity of water-borne hyphomycetes in stemflow and throughfall of 14 non-riparian tree species (see Table 1 for details of tree species).

Discussion

Even though water-borne fungi are very common on submerged leaf litter in streams, their repeated occurrence in tree canopies confirms their intimate association with canopies. They have been reported from a variety of canopy habitats such as stemflow, throughfall, intact leaves, trapped leaf litter, canopy snow, tree holes and epiphytes (Sridhar *et al.* 2006, Gönczöl & Révay 2006, Karamchand & Sridhar 2008, Czeczuga & Orłowska 1999). Some typical aquatic hyphomycetes were also the component of rainwater flowing through the roof gutters of buildings in Poland (e.g., *Arbusculina irregularis, Clavariana aquatica, Colispora elongata, Lunulospora curvula*) (Czeczuga & Orłowska 1997). Based on examinations of dew and rain drops on intact tree leaves in misty habitats, Ando (1992) and Ando and Kawamoto (1989) predicted that certain fungi with branched conidia possessing micronematous conidiophores (short conidiophores) have been evolved on trees rather than in streams (e.g., *Alatosessilispora, Arborispora, Ceratosporium, Curucispora,Dicranidion, Dwayaangam, Microstella, Ordus, Retiarius, Titaea, Titaeella, Tricladiella, Tridentaria, Trifurcospora, Trinacrium, Tripospermum, Trisulcosporium*). Another important feature of such canopy hyphomycetes is their staurosporous conidia adapted to hold water around the conidium facilitating quick germination.

So far, up to 118 species of water-borne hyphomycetes have been reported from different habitats of tree canopies (Sridhar 2009). The present study revealed 63 species, among them 19 species which were previously not known from tree canopies (see Table 2). Among the fungi recovered in the present study, *Anguillospora crassa, A. longissima, Flagellospora curvula, Trinacrium subtile, Triscelophorus acuminatus,* and *T. konajensis* were common in tree canopies. Compared with the high diversity of water-borne fungi in banyan (*Ficus benghalensis*) tree holes (Karamchand and Sridhar 2008), the current study also revealed the highest diversities in stemflow and throughfall of banyan (see Fig. 3). Depending on the surface runoff, the fungal assemblage and diversity may differ in tree species as seen in banyan vs. other tree species in our study. Submerged banyan leaf litter in the Konaje stream near the Mangalore University Campus also harbors more species of aquatic hyphomycetes contrasting to leaf litter of other tree species (Sridhar & Kavariappa 1989, Sridhar *et al.* 1992).

Among the 63 species recorded in the present study, most of them have multiradiate conidia (three conventional, six sigmoid, six helicosporus, and 48 multiradiate). The majority of spores found in the tree canopy habitats belonged to the multiradiate type (Sridhar 2009). These conidia might have adapted to canopy habitats and their branched nature may resist removal from the leaf or bark surface. The 'Aqueous film theory' depicts the movement of spores in an aqueous film on wet leaves or on bark facilitating the transport of conidia (Bandoni 1974, Bandoni & Koske 1974). The tree hole inhabiting insects (Kitching 1971) might also propagate fungal propagules adhered to their body or through their feces within or across the canopies. The teleomorphs of many aquatic hyphomycetes have been seen in plant detritus from terrestrial habitats near the streams (Webster 1992). Woody litter in terrestrial habitats and emergent portions of riparian vegetation also consists of teleomorphs of water-borne hyphomycetes (Webster 1992, Shearer 1992). The spores of such teleomorphs might traverse through the air, and the canopy hyphomycetes might disseminate asexual propagules to streams or terrestrial habitats via air, stemflow, throughfall or invertebrates. There is a risk of extinction of water-borne fungi due to unidirectional flow of stream water. They overcome such risks through colonizing the stationary substrates in stream column and stream banks (e.g., wood, roots) (Shearer 1992, Bärlocher 2006). Alternatively, tree canopy habitats (e.g., leaves, bark, tree holes, and epiphytes) also serve as potential refuge for these fungi. Selosse *et al.* (2008) proposed the hypothesis that the shape of conidia of aquatic hyphomycetes besides evolved for dispersal in water, their congregation in air bubbles of stream foam facilitate dispersal via wind or aerosol transport of aquatic hyphomycetes to tree canopies. Carroll (1981) emphasized that the conidial fungi constitute a guild in tree canopies and serve in the food web similar to that of aquatic hyphomycetes in streams. Water-borne fungi might have evolved to survive in tree canopies similar to stream fungi. For instance, *Tricladium* and *Anguillospora* spp. belong to the Helotiales, which are well known as plant endophytes (Vrålstad *et al.* 2002). Typical aquatic/water-borne hyphomycetes (*Dwayaangam colodena, Retiarius* sp., *Tripospermum camelopardus*, and *T. myrti*) have also been reported as endophytes in black spruce canopy needles (*Picea mariana*) in a mixed wood forest of Canada (Sokolski *et al.* 2006ab). Recent molecular techniques confirmed the multiple origins of several aquatic hyphomycetes (Belliveau and Bärlocher 2005, Campbell *et al.* 2006) and ascomycetes (Kong *et al.* 2000, Liew *et al.* 2002) with terrestrial relatives. The helicosporus fungi are also common in tree canopies (see Table 2). Their conidia adapted to entrap air bubbles as a means to float and disperse in water. Molecular evidences recently gathered by Tsui and Berbee (2006) identified six convergent lineages of helicosporous fungi in ascomycetes and many of them belonged to Tubeufiaceae (Dothideomycetes) and speculated that their spore forms convergently evolved for dispersal in aquatic habitats.

Although there have been extensive studies on community patterns and ecological functions of water-borne fungi in woodland streams, their vertical distribution and ecological functions in riparian tree canopies is largely unknown. Stone *et al.* (1996) have opined that canopy fungi as early colonizers of live foliage and twigs may assist as a minor link between soil and aquatic food webs by completing their life cycles. Several morphologically different conidia recovered in stemflow, throughfall, and tree holes have not been identified even to generic level (Gönczöl & Révay 2003, 2004, 2006) indicating the existence of a diverse mycobiota in canopies. Basic understanding of the distribution of plants, animals and microbes in forest canopies is vital for estimating energy flow, carbon cycling, resource utilization and transfer of materials within and across the canopy ecosystems. It is known that stemflow and throughfall consist of several minerals (e.g., N, P, K, Ca, and Mg) (Schroth *et al*. 2001, Bradley *et al*. 2007). As in streams, the canopy fungi may also meet their mineral requirements through canopy run off. Interestingly, floral honey or honeydew excreted by aphids can also serve as ecological niches for some fungi (Magyar *et al*. 2005). Estimates of microfungal biomass in twigs and needle surfaces of old-growth Douglas fir forest canopies were up to 450 kg/ha/yr (Carroll *et al*. 1980) indicating an important role of microfungi in canopy food webs. There seems to be a spatial and temporal variability of water-borne fungi in canopies. As the information on the role of water-borne fungi in canopies is fragmentary, molecular techniques are essential in addition to traditional techniques to clarify their structural and functional significance in these habitats.

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