Diversity of filamentous fungi on woody litter of five mangrove plant species from the southwest coast of India

G.L. Maria[1] and K.R. Sridhar[2*]

[1]Department of Botany, St. Agnes College, Mangalore 575 002, Karnataka, India
[2]Department of Biosciences, Mangalore University, Mangalagangotri 574 199, Mangalore, Karnataka, India

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Fungal diversity on decaying intertidal wood of five mangrove plant species (*Acanthus ilicifolius, Avicennia officinalis, Bruguiera gymnorrhiza, Rhizophora mucronata* and *Sonneratia caseolaris*) accumulated on the floor of Udyavara mangrove stand of southwest coast of India was investigated. Wood samples collected during the monsoon and summer season were incubated in moist chambers and observed once every two weeks for up to six months. Ninety-one fungi belonging to 68 genera were recovered. Terrestrial fungi were dominant during the monsoon season, while marine fungi were dominant during the summer. Fungal richness and diversity were higher during the monsoon season than the summer. *Rhizophora mucronata* showed the highest Simpson's index at both seasons. The Shannon index was highest for *Rhizophora mucronata* in the monsoon season, while it was highest for *Bruguiera gymnorrhiza* during the summer. Rarefaction showed the highest expected number of species out of 150 identifications was from *Rhizophora mucronata* during the monsoon season (43 vs. 27-38 species), while it was highest in *Sonneratia caseolaris* during the summer (25 vs. 20-23 species). Maximum number of species per sample was observed on *Bruguiera gymnorrhiza* (monsoon, 2.9; summer, 3). Significant differences in the species diversity and expected number of species between the seasons were seen (t-test). *Lignincola laevis, Savoryella lignicola* and *Trichocladium linderi* were found in both seasons on all substrata. *Lignincola laevis, Passeriniella mangrovei, Savoryella lignicola, S. paucispora, Trichocladium achrasporum* and *T. linderi* were dominant during the monsoon season (>10%), while *Cirrenalia pygmea, Lignincola laevis, Lulworthia grandispora, Nais* sp., *Savoryella lignicola* and *Zalerion varium* were dominant during the summer. It is likely that terrestrial, freshwater and aero-aquatic fungi find ideal conditions for their development in mangroves during the monsoon season in the west coast of India.

Keywords: diversity, filamentous fungi, mangroves, woody litter

Introduction

Among the marine ecosystems in the tropics, mangroves are important next to coral reefs in gross productivity (Qasim and Wafar, 1990). Two

[*]Corresponding author. email: sirikr@yahoo.com

essential biological processes in the mangroves are the accumulation of synthesized energy (e.g. litter products) and the conditioning of the organic matter (decomposition) for immediate transfer of energy to the higher trophic levels (Wafar *et al*., 1997). Microorganisms play an important role in the decomposition of plant detritus and energy flow in mangrove food webs (Odum and Heald, 1975; Cundell *et al*., 1979; Fell and Master, 1980; Tenore *et al*, 1982). However, the proportion of woody litter entering the marine detritus pathway is not clearly understood (Robertson, 1987). Out of 900 known marine fungi, 358 are found in mangrove ecosystems, where ascomycetes are common (Jones and Kuthubutheen, 1989; Kohlmeyer and Volkmann-Kohlmeyer, 1991; Alias *et al*., 1995; Jones and Alias, 1996; Jones and Mitchell, 1996). Although several obligate marine fungi have been recovered from mangroves (Kohlmeyer and Kohlmeyer, 1979; Jones, 1993), few studies have assessed the mycota of fungal flora on detritus of specific mangrove plant species (e.g. Hyde, 1990; Sarma and Vittal, 2001). The terrestrial fungi in mangrove ecosystems are facultative and generally are ignored as transient mycota (Raghukumar, 1996; Chandralata, 1999; Jones, 2001).

Peninsular India encompasses about 6700 km^2 of mangrove forest consisting of two types of habitats: the deltaic east coast (Bay of Bengal) and backwater-estuarine west coast (Arabian Sea) (Natarajan, 1998; Kathiresan, 1999). Although some studies are available on the mangrove mycota of the Indian peninsula, few studies have dealt with fungal richness and diversity (west coast: Borse, 1988; Borse *et al*., 2000; Patil and Borse, 2001; east coast: Ravikumar and Vittal, 1996; Sarma and Vittal, 2000, 2001). In contrast, there is no information on the species richness and diversity of higher fungi on specific mangrove woody debris of southwest coast of India. Hence, the present investigation aims at understanding the richness and diversity of higher fungi on five mangrove woody debris collected from a mangrove habitat at the southwest coast of India during the monsoon and summer seasons.

Materials and methods

Sampling site

Udyavara mangrove is established at the Udyavara and Katpady river mouths of the Karnataka coast. Among the mangroves of Karnataka, relatively large undisturbed mangrove stands exist. The most common plant species are *Acanthus ilicifolius, Avicennia officinalis* and *Rhizophora mucronata*. Udyavara mangrove has a humid tropical climate with rainy periods during June-November (monsoon) and dry periods during December-May (summer). During the monsoon season the mangrove floor is inundated with freshwater, subsequently freshwater flow from rivers decreases, which results in intrusion of seawater and therefore increase in the salinity. The salinity of mangrove water was 0-1.5‰ from June to November, 5-18‰ during December to January and 34-35‰ during March-May. The water temperature fluctuated between 22-33ºC, while the pH was neutral to alkaline (6.7-7.7). During the monsoon season (October 1999) water salinity, temperature and pH were 1.05‰, 26.5ºC and 6.7 respectively, while during the summer season (March 2000) they were 31.9‰, 31ºC and 7.7 respectively (APHA, 1995).

Sampling, incubation and observation

Fallen and partially decomposed wood samples (twigs and branches) of five plant species: *Acanthus ilicifolius*, *Avicennia officinalis*, *Bruguiera gymnorrhiza*, *Rhizophora mucronata* and *Sonneratia caseolaris* accumulated on the mangrove floor were collected from a plot of 0.5 km^2 during the monsoon (October 1999) and summer (March 2000) seasons. Wood samples of about 2 cm diam. were selected and cut into 20 cm lengths. They were scanned for the fungal structures within one week of collection, later incubated in polythene bags at 27 ± 2ºC containing sterile sand wetted with sterile mangrove water. Subsequently the samples were examined once every two weeks for up to six months for fungal sporulation. Fungi developing on the wood were identified based on the monographs and descriptions (Kohlmeyer and Kohlmeyer, 1979; Kohlmeyer and Volkmann-Kohlmeyer, 1991).

Data analyses

Frequency of occurrence (%) of fungi on each host plant species and the mean number of fungi per wood sample were calculated as follows:

$$\text{Frequency of occurrence (\%)} = \frac{\text{Total number of wood colonized by a specific fungus}}{\text{Total number of wood supporting sporulating fungi}} \times 100$$

$$\text{Mean number of fungi per sample} = \frac{\text{Total number of fungal isolations}}{\text{Number of wood with sporulating fungi}}$$

One-way ANOVA was employed to determine the differences in the frequency of occurrence of fungi on each host. Difference in the total percent frequency of occurrence of fungi during monsoon and summer was analyzed by paired t-test (MICROSTAT, Ecosoft Inc., 1984).

The diversity of fungi on five hosts during monsoon and summer season was assessed based on the diversity indices (Magurran, 1988):

$$\text{Simpson's index, } D' = \frac{1}{\sum (p_i)^2}$$

$$\text{Shannon index, } H' = - \sum (p_i \ln p_i)$$

where, p_i is the proportion of individual that species i contribute to the total number of individuals.

The Shannon evenness, J', was expressed by:

$$J' = \frac{H'}{H'_{max}}$$

where, H'_{max} is the maximum value of diversity for the number of species present (Pielou, 1975).

Paried t-test was performed to determine the seasonal differences in diversity (Simpson's index and Shannon index) and expected number of species (MICROSTAT, Ecosoft Inc., 1984). To compare the species richness among the wood samples of each host of unequal size during two seasons, rarefaction indices were calculated (Ludwig and Reynolds, 1988). The expected number of fungal species, $E_{(s)}$, in a random sample of n isolations taken from a total population of N isolations was calculated using the formula:

$$\text{E(s)} = \sum_{i=1}^{s} \left\{ 1 - \left[\binom{N - n_i}{n} \Big/ \binom{N}{n} \right] \right\}$$

where, n_i is the number of isolations of ith species.

Jaccard's index of similarity (JI) was calculated pair-wise among the hosts based on the presence or absence of each fungal species irrespective of the season (Kenkel and Booth, 1992):

$$JI = c/(a+b+c),$$

where, c is the number of fungal species occurring in both hosts, a is the number of fungal species unique to the first host and b is the number of fungal species unique to the second host.

Results

Fungal assemblages

Analysis of 1008 wood samples revealed the fungal colonization on 99% of samples, which yielded 2561 identifications. The number of identifications and the mean number of fungi per sample were higher in the summer than in the monsoon season on all hosts except for *Avicennia officinalis* (Table 1). The

Table 1. Fungal assemblage, diversity and species richness on five mangrove woody litter during monsoon (M) and summer (S).

Hosts		Assemblage*				Diversity			Species richness (S')	
		Sc	Sco	Fi	Fps	(D')	(H')	(J')	Total species	$E_{(s150)}$**
Acanthus ilicifolius	M	106	100	214	2.1	0.908	4.200	0.812	36	32
	S	106	103	263	2.6	0.880	3.444	0.797	20	18
Avicennia officinalis	M	103	103	297	2.9	0.939	4.507	0.826	44	35
	S	100	100	262	2.6	0.863	3.434	0.740	25	20
Bruguiera gymnorrhiza	M	102	100	286	2.9	0.896	4.340	0.777	48	38
	S	100	100	297	3	0.902	3.782	0.787	28	23
Rhizophora mucronata	M	104	104	210	2	0.948	4.810	0.852	50	43
	S	100	100	243	2.4	0.903	3.710	0.809	24	20
Sonneratia caseolaris	M	80	79	190	2.4	0.886	3.868	0.788	30	27
	S	107	107	299	2.8	0.876	3.689	0.776	27	25
Mean ± SD (n = 5)	**M**	**99 ± 9.7**	**97 ± 9.2**	**239 ± 43.5**	**2.5 ± 0.5**	**0.915 ± 0.02**	**4.345 ± 0.31**	**0.811 ± 0.03**	**41.6 ± 7.53**	**35 ± 5.40**
	S	**103 ± 3.1**	**102 ± 2.9**	**273 ± 21.7**	**2.7 ± 2.7**	**0.885 ± 0.02**	**3.612 ± 0.15**	**0.782 ± 0.02**	**24.8 ± 2.79**	**21.2 ± 2.48**

*Assemblage: Sc, Number of samples collected; Sco, Number of samples colonized; Fi, Number of fungal isolations; Fps, Number of fungi per sample.
**$E_{(s150)}$: Expected number of species out of 150 isolations.

maximum number of fungi was recovered on all hosts during monsoon season (mean: 41.6 vs. 23.8). Both ascomycetes and anamorphic fungi were higher during monsoon than in the summer season (ascomycetes, 34 vs. 25; anamorphic fungi, 43 vs. 22). The total number of fungi irrespective of the seasons were highest in *Bruguiera gymnorrhiza* and *Rhizophora mucronata* (58 species) followed by *Avicennia officinalis* (57), *Sonneratia caseolaris* (43) and *Acanthus ilicifolius* (42). Altogether 91 fungi belonging to 68 genera were recorded on five hosts (42 ascomycetes, 46 anamorphic fungi and three basidiomycetes). Seventy-nine and forty-nine fungi were found on the monsoon samples and the summer samples respectively. Table 2 lists the frequency of occurrence of fungi on each host during monsoon and summer. No significant difference was found in the percentage frequency of occurrence of all fungal species on the five hosts irrespective of the season ($p > 0.05$, ANOVA), and between the total percent frequency of occurrence of fungi during monsoon and summer (paired t-test).

Table 2. Frequency of occurrence (%) of filamentous fungi on five mangrove woody litter during the monsoon (M) and summer (S) seasons (fungi found on all hosts are given in bold face).

Taxon	Hosts*					Total frequency (%)
	Ai	**Ao**	**Bg**	**Rm**	**Sc**	
Season	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**
Ascomycotina						
†*Aniptodera chesapeakensis* Shearer & M.A. Mill.	4,12.6	0.4,-	-	-	-	0.8,2.6
†*Aniptodera indica* K. Ananda & K.R. Sridhar	2,2.9	-,1	-,11	-,7	-,26.2	0.4,9.9
†*Aniptodera mangrovei* K.D. Hyde	4,-	1.9,3	2,10	4.8,5	3.7,0.9	3.3,3.7
Antennospora quadricornuta (Cribb & J.W. Cribb) T.W. Johnson	1,-	-	-	0.9,-	-	0.4,-
Bombardia sp.	-	-	-	-	1.3,-	0.2,-
Caryosporella rhizophorae Kohlm.	-	0.9,-	1,-	0.9,-	-	0.6,-
Ceriosporopsis sundica J. Koch & E.B.G. Jones	-	-	2,-	0.9,-	-	0.6,-
Coronopapilla mangrovei (K.D. Hyde) Kohlm. & Volkm.-Kohlm.	-	-	-	0.9,-	1.3,-	0.4,-
Dactylospora haliotrepha (Kohlm. & E. Kohlm.) Hafellner	-	-,2	-	-	-	-,0.4
Didymella avicenniae S.D. Patil & Borse	-	-,1	-	-	-,1.9	-,0.6
Durella sp.	-	0.9,-	-	5.8,-	2.5,-	1.9,-
Eutypa bathurstensis K.D. Hyde & Rappaz	-	0.9,-	-	0.9,-	-,0.9	0.4,0.2
Halorosellinia oceanica Whalley, E.B.G. Jones, K.D. Hyde & Laessøe	-	-	1,1	3.8,-	-,0.9	1,0.4
Halosarpheia cincinnatula Shearer & J.L. Crane	-	-,1	2,1	1.9,4	-	0.8,1.2
Halosarpheia fibrosa Kohlm. & E. Kohlm.	-	5.8,-	1,-	-	3.7,-	2.1,-
Halosarpheia ratnagiriensis S.D. Patil & Borse	-,3.9	1.9,-	-	-,4	-,6.5	0.4,3
Hypoxylon sp.	-	-	-	-,0.9	-	-,0.2

Table 2. (continued).

Taxon	**Hosts***					**Total frequency (%)**
	Ai	**Ao**	**Bg**	**Rm**	**Sc**	
Season	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**
Kallichroma tethys (Kohlm. & E. Kohlm.) Kohlm. & Volkm.-Kohlm.	2,-	1.9,-	6,-	0.9,0.1	-,1.9	2.3,0.6
Lautitia danica (Berl.) S. Schatz	1,-	-	-	-	-	0.2,-
†*Leptosphaeria australiensis* (Cribb & J.W. Cribb) G.C. Hughes	-,26	-,2	-	-	-	-,5.5
Leptosphaeria peruviana Speg.	-	-	-,1	-	-	-,0.2
Leptosphaeria sp.	1,-	-	2,-	-	-	0.6,-
†*Lignincola laevis* Höhnk	19,40.8	12.6,81	15,3	3.8,29	8.8,6.5	12,33.5
Lignincola tropica Kohlm.	-	7.8,-	2,-	-	-	1.9,-
Lophiostoma mangrovei Kohlm. & Vittal	1,-	-	1,-	0.9,-	1.3,2.8	0.6,0.6
†*Lulworthia grandispora* Meyers	-,14.5	4.8,44	9,8	30,43	2.5,4.7	9.7,22.5
Lulworthia sp. (350-400 µm)	-	-,9	-	-,5	-,1.9	-,3.1
Massarina velatospora K.D. Hyde & Borse	-	-	1,-	-	-	0.2,-
Mycosphaerella salicorniae (Auersw.) Petr.	-	-	1,-	-	-	0.2,-
†*Nais* sp.	-	1.9,33	3,7	5.8,14	8.8,0.9	3.8,10.8
†*Passeriniella mangrovei* G.L. Maria & K.R. Sridhar	-	34.9,-	25,-	10.6,-	-	14.6,-
Phomatospora sp.	-	-	1,-	-	-	0.2,-
†*Savoryella lignicola* E.B.G. Jones & R.A. Eaton	11,0.9	12.6,13	16,11	14.3,1	11.3,58	13.2,17
†*Savoryella longispora* E.B.G. Jones & K.D. Hyde	2,-	1.9,3	-,10	-,1	-	1,2.6
†*Savoryella paucispora* (Cribb & J.W. Cribb) J. Koch	10,-	20.4,13	10,24	0.9,9	10,3.7	10.3,9.9
†*Verruculina enalia* (Kohlm.) Kohlm. & Volkm.-Kohlm.	12,8.7	3.8,-	3,-	3.8,2	3.7,9.3	5.4,4.1
†*Zignoella* sp.	12,-	0.9,-	7,-	2.9,-	3.7,-	5.4,-
Zopfiella latipes (Lundqvist) Malloch & Cain	-	1.9,-	1,	-	3.7,-	1.3,-
†Ascomycete 1	-	25.2,-	7,-	4.8,-	8.8,-	9.3,-
Ascomycete 2	-	3,9	-	-	-	0.8,1.8
†Ascomycete 3	-	-,3	-	-,16	-	-,3.7

Table 2. (continued).

Taxon	Hosts*					Total frequency (%)
	Ai	**Ao**	**Bg**	**Rm**	**Sc**	
Season	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**
†Ascomycete 4	-	-,20	-,2	-,16	-	-,7.7
Basidiomycotina						
Auricularia sp	-	0.9,-	-	-	-	0.2,-
†*Halocyphina villosa* Kohlm. & E. Kohlm.	2,26.2	-,1	-	-,3	-	0.4,6.1
Schizophyllum sp.	-	-	-,1	-	-	-,0.2
Anamorphic fungi						
†*Acremonium* sp.	4,26.2	2.9,-	2,8	0.9,1	5,32.7	2.1,9.4
Alternaria sp.	4,-	3.8,-	3,1	0.9,-	1.3,-	3,0.2
Anguillospora marina Nakagiri & Tubaki	-	-	-	0.9,-	-	0.2,-
Arthrobotrys oligospora Fresen.	1,-	-	1,-	0.9,-	-	0.6,-
Aspergillus sp.	4,0.9	-	1,-	-	-,1.9	1,0.6
Brachysporiella gayana Batista	-	0.9,-	-	1.9,-	1.3,-	0.8,-
Cirrenalia macrocephala (Kohlm.) Meyers & R.T. Moore	-,1	0.9,-	-	3.8,1	1.3,-	1.7,0.2
†*Cirrenalia pygmea* Kohlm.	-,2.9	-,11	-,47	2.9,37	-,2.8	6,20
Cirrenalia tropicalis Kohlm.	2,-	-,3	2,1	2.9,7	-	1.5,2.1
Clavatospora bulbosa (Anast.) Nakagiri & Tubaki	-	-,1	-	-	-	-,0.2
Codinaea sp.	-	-	2,-	-	-	0.4,-
Curvularia geniculata (Tracy & Earle) Boedijn	-	-	1,-	-	-	0.2,-
Custingophora olivacea Stolk, Hennebert & Klopotek	1,-	-	-	-	-	0.2,-
Cytospora rhizophorae Kohlm & E. Kohlm.	-	-	-,2	-	-	-,0.4
Dactylella sp.	-	0.9,-	-	-	-	0.2,-
Delortia palmicola Pat.	1,-	-	4,-	0.9,-	-	1,-
Diplocladiella scalaroides G. Arnaud *ex* M.B. Ellis	-	2.9,-	1,-	-	-	0.8,-
Endophragmia alternata Tubaki & Saito	2,-	-	4,-	4.8,-	1.3,-	2.5,-
Graphium sp.	1,-	1.9,-	-	-	-	0.4,-
Helicoma muelleri Corda	-	-	-	0.9,-	-	0.2,-

Table 2. (continued).

Taxon	**Hosts***					**Total frequency (%)**
	Ai	**Ao**	**Bg**	**Rm**	**Sc**	
Season	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**	**M,S**
Helicomyces roseus Link.	-	1.9,-	2,-	5.8,-	-	2.3,-
Menispora ciliata Corda	-	-	2,-	0.9,-	-	0.6,-
Monodictys pelagica (T.W. Johnson) E.B.G. Jones	4,-	1.9,-	4,-	0.9,-	-	2.3,-
Monodictys putredinis (Wallr.) S. Hughes	3,-	8.7,-	-	0.9,-	-	0.8,-
Leptosphaeria salvinii Cattaneo (anamorph, nakatea state)	-	-	-	1,-	-	0.2,-
Penicillium sp. 1	5,-	1.9,-	3,-	0.9,1	1.3,-	2.5,2
Penicillium sp. 2	-	-	4,2	1.9,-	-	1.3,0.4
†*Phaeoisaria clematidis* (Fuckel) Hughes	-	14.5,-	5,1	2.9,-	16.3,-	6,-
Phaeosphaeria sp.	1,-	-	1,-	-	-	0.4,-
Periconia prolifica Anast.	-	0.9,1	-	-	1.3,9.3	0.4,2.4
†*Phoma* sp.	-,1.9	19.4,-	-,1	3.8,-	17.5,-	5.8,0.4
Phomopsis sp.	1,4.8	-	-,2	-	-,1.9	0.2,1.2
†*Sporidesmium* sp. 1	5,-	1.9,-	7,2	1.9,-	35,6.5	9.1,0.4
Sporidesmium sp. 2	-	0.9,-	-	-	3.7,-	0.8,-
†*Stachybotrys oenanthes* M.B. Ellis	13,1.9	-	-	-	-,0.9	2.8,0.6
Stachylidium bicolor Link	-	-	-	*1.9,-*	-	*0.4,-*
Stilbum sp.	-	-	-,1	-	-	-,0.2
Taeniolella stricta (Corda) S. Hughes	-	-	2,-	0.9,-	-	0.6,-
Tetracrium sp.	-	-	-	0.9,-	-	0.2,-
†*Trichocladium achrasporum* (Meyers & R.T. Moore) Dixon	15,2.9	13.6,-	16,44	4.8,-	6.3,4.7	11.4,10
Trichocladium alopallonellum (Meyers & R.T. Moore) Kohlm. & Volkm.-Kohlm.	-	2.9,2	-	2.9,-	-	1.3,0.4
†*Trichocladium linderi* J.L. Crane & Shearer	55,2.9	38,1	79,15	20.2,2	64,7.4	50,5.7
Trichocladium sp.	-	-,1	2,-	-	-,0.9	0.4,0.4
Verticillium sp.	3,-	2.9,-	1,-	2.9,-	1.3,-	1.7,-
†*Zalerion maritimum* (Linder) Anast.	2,7.8	10.7,-	7,17	14.3,10	3.7,7.4	8,8.4
†*Zalerion varium* Anast.	6,56.3	3.8,24	2,45	9.6,26	-,6.5	4.5,32

*Hosts: Ai, *Acanthus ilicifolius;* Ao, *Avicennia officinalis;* Bg, *Bruguiera gymnorrhiza;* Rm, *Rhizophora mucronata;* Sc, *Sonneratia caseolaris*.
†"Core-group fungi" (frequency of occurrence > 10%).

Frequent and rare fungi

Lignincola laevis, Sarvoryella lignicola and *Trichocladium linderi* were recovered on all substrata during both seasons. *Trichocladium linderi* was the most frequent fungus (50%) in monsoon followed by *Passeriniella mangrovei* (14.6%), *Savoryella lignicola* (13.2%), *Lignincola laevis* (12%), *Trichocladium achrasporum* (11.4%) and *Savoryella paucispora* (10.3%). The dominant fungus during summer was *Lignincola laevis* (33.5%) followed by *Zalerion varium* (32%), *Lulworthia grandispora* (22.5%), *Cirrenalia pygmea* (20%), *Savoryella lignicola* 17%), *Nais* sp. (10.8%) and *Trichocladium achrasporum* (10%).

Twenty-three fungi found on any one of the five hosts are considered as "rare fungi". The frequency of occurrence of rare fungi ranged between 0.9 and 2% (except for Ascomycete sp. 2: 3-9%). Among 22 rare fungi, 12 were marine, 8 were terrestrial and 2 were aero-aquatic fungi. Fifteen rare species were recorded exclusively during monsoon, while the rest were recorded in summer.

"Core-group fungi" on hosts

Frequent fungi (> 10%) on any host were considered as "core-group fungi". Altogether 27 fungi belonged to the core-group (Table 2). The number of frequent fungi was highest on *Avicennia officinalis* (15) and lowest on *Acanthus ilicifolius* (8). *Lignincola laevis, Savoryella lignicola* and *S. paucispora* were dominant during the monsoon and summer seasons on at least two hosts. During the monsoon season *Savoryella lignicola* and *Trichocladium linderi* were dominant on all hosts, but none of the core-group of fungi were dominant on all hosts during summer.

Diversity of fungi

Table 1 provides the diversity and species richness of fungi on five hosts. Among the hosts, Simpson index was highest in *Rhizophora mucronata* for both seasons (monsoon: 0.948 vs. 0.886-0.939; summer: 0.903 vs. 0.863-0.902). The Shannon index was highest for *Rhizophora mucronata* during the monsoon season (4.810), and for *Bruguiera gymnorrhiza* in summer season (3.783 vs. 3.434-3.710). However, the mean data of all hosts shows the highest Simpson and Shannon indices during the monsoon season (0.915; 4.345) than during the summer (0.885; 3.612). Hence, during monsoon both common and rare fungi were diverse on woody litter. The Shannon evenness was also highest in *Rhizophora mucronata* for both seasons (monsoon: 0.852 vs. 0.777-0.826; summer: 0.809 vs. 0.740-0.787). Rarefaction based on the number of species expected in a random sample of 150 identifications, $E_{(s150)}$, on each host indicated that *Rhizophora mucronata* had the richest mycota during the monsoon season (43 vs. 27-38 species), while for summer it was *Sonneratia caseolaris* (25 vs. 20-23 species) (Table 1). Mean data revealed the highest species richness during the monsoon season (35 vs. 21.2 species). Figure 1 shows the rarefaction curves for five hosts during the monsoon and summer seasons. Jaccard's index of similarity of fungi on five hosts in both seasons ranged between 0.2-0.39 indicating considerable dissimilarity of fungal assemblages (61-80%) among the five hosts. Paired t-tests revealed significant seasonal differences in the Simpson index ($p = 0.04$), Shannon index ($p = 0.006$) and the expected number of species ($p = 0.007$).

Discussion

Fungal community

Examination of woody litter provides basic information on the fungal community of a particular mangrove habitat (Tan and Leong, 1992). Mangroves are now considered as the second most important host for marine fungi after driftwood (Hyde *et al*., 2000). The present study reveals considerable diversity in the assemblage of fungi on woody substrata of five hosts during the monsoon and summer seasons. Significant differences were seen in the species diversity (Simpson and Shannon indices) and the expected number of species between the monsoon and summer seasons (paired t-test). A few quantitative studies on fungi are available from the mangroves of the Indian subcontinent for comparison. There were drastic differences in the fungal composition and their frequency of occurrence between the west coast and the east coast of India. The common fungi in the present study viz., *Aniptodera mangrovei, Cirrenalia pygmea, Lignincola laevis* and *Savoryella lignicola* are not common in the east coast mangroves (Sarma and Vittal, 2001). Also the dominant fungi *Dactylospora haliotrepha* and *Verruculina enalia* on the wood of *Rhizophora apiculata* (Sarma and Vittal, 2000), and *Lophiostoma mangrovei* and *Verruculina enalia* on the wood of *Rhizophora* spp. from the east coast (Ravikumar and Vittal, 1996) are not dominant on *Rhizophora mucronata* in our study. Similarly, dominant *Eutypa bathurstensis* and *Verruculina enalia* on wood of *Avicennia* spp. from the east coast (Sarma and Vittal, 2000) were not dominant on *Avicennia officinalis* in the present study. These differences may be attributed to the differences in the mangroves between the east (deltaic) and the west coast (backwater-estuarine).

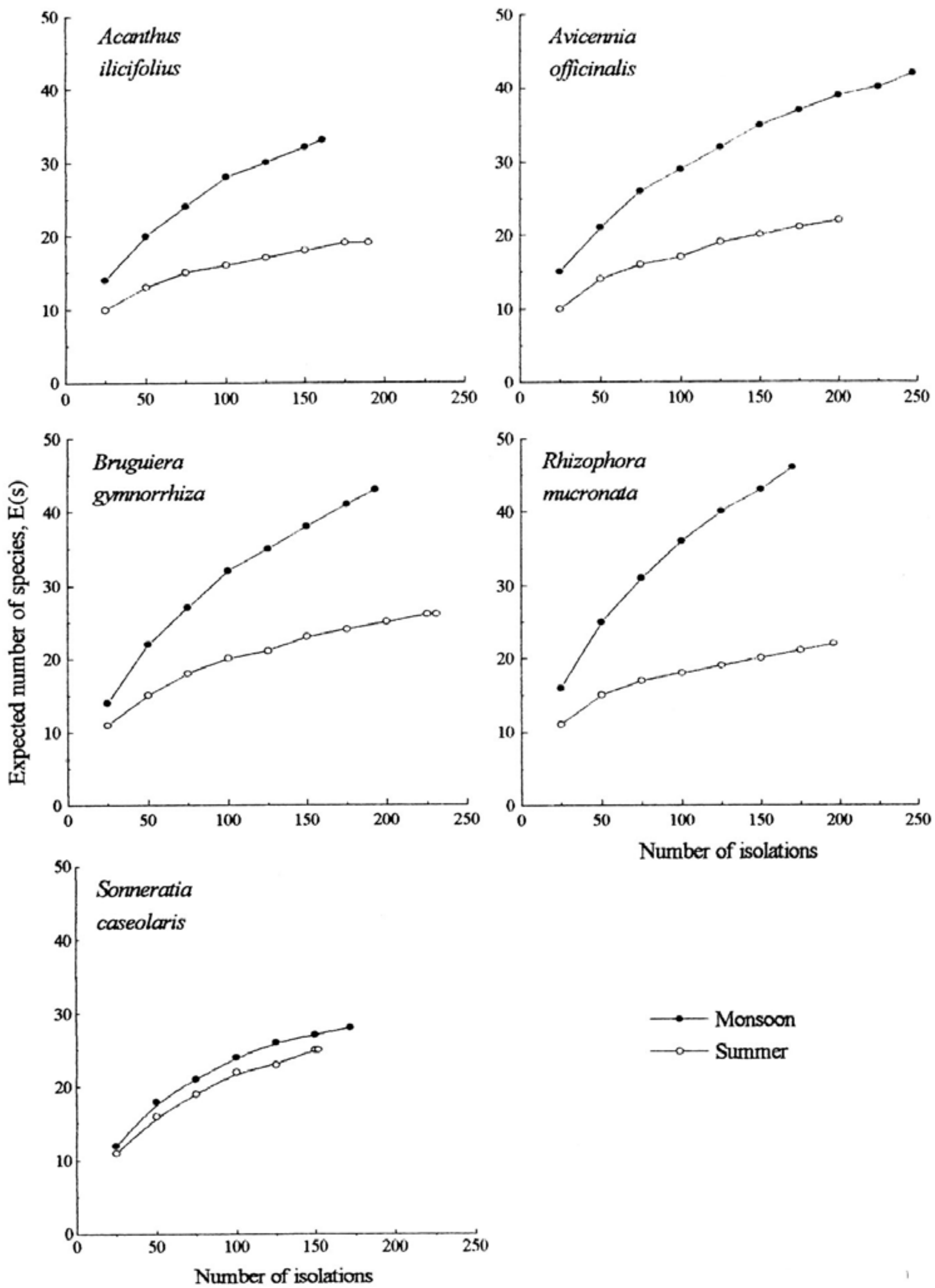

Fig. 1. Rarefaction curves of expected number of species, $E_{(s)}$, out of 150 isolations of filamentous fungi recovered from the woody litter of five mangrove plant species during monsoon and summer.

East coast mangroves, being deltaic, are more diverse in vegetation than the mangroves of west coast. Differences in the fungal communities between the present study and other studies of the west coast of India (Maharashtra and Gujarat) are also evident. In the mangroves of Maharashtra, *Aigialus grandis, Dactylospora haliotrepha, Halocyphina villosa, Massarina velatospora* and *Verruculina enalia* were dominant (Borse, 1988). These fungi, except for *Halocyphina villosa* and *Verruculina enalia* are not dominant in our study. Similarly in mangroves of Gujarat, *Aigialus parvus, Dactylospora haliotrepha, Julella avicenniae, Kallichroma tethys, Lulworthia grandispora* and *Periconia prolifica* were dominant (Borse *et al*., 2000; Patil and Borse, 2001). Except for *Lulworthia grandispora* these dominant fungi in Gujarat mangrove are infrequent in the present study. Among the core-group of fungi in the present study, *Lignincola laevis* and *Lulworthia grandispora* are common in the mangroves of the Indian and Pacific Oceans and South-East Asia (Sarma and Hyde, 2001). *Cirrenalia pygmea* is dominant in the Indian Ocean and South-East Asia (Sarma and Hyde, 2001). *Savoryella lignicola, S. paucispora* and *Trichocladium achrasporum* are dominant in South-East Asia (Sarma and Hyde, 2001). The availability of substrata for fungal colonization is crucial in governing the diversity of fungi in mangrove ecosystems (Jones and Alias, 1996). The oceanic region, tidal inundation, nature of floor, type of wood (soft, hard or herbaceous), salinity and pH also affect the occurrence of fungi in mangrove ecosystem (Hyde and Jones, 1988). In addition, the length of monsoon season and the extent of disturbance (human interference: deforestation and pollution) might also affect fungal communitiy, diversity and their functions in mangrove ecosystem.

Anamorphic fungi were common in estuarine environment, while ascomycetes dominate fully marine conditions (Jones and Hyde, 1988). In the present study, the number of anamorphic fungi was higher than that of ascomycetes during the monsoon season (43 vs. 34 species), and almost equal during the summer (22 vs. 25 species). Although *Lignincola laevis, Lulworthia grandispora, Savoryella lignicola, S. paucispora, Trichocladium achrasporum, Verruculina enalia* and *Zalerion maritimum* are marine fungi, they were dominant (> 10%) on at least one of the hosts during monsoon season when the salinity was as low as 1.05‰ (Table 2).

Fungal richness on wood

The fungal richness in the present study ranged between 42 (*Acanthus ilicifolius*) and 58 (*Avicinnia officinalis* and *Rhizophora mucronata*). Sarma and Vittal (2001) also recorded a maximum of 64 fungi on woody litter of *Rhizophora apiculata* followed by *Avicennia officinalis* (55 species) from the mangroves of east coast of India. The data on the mean number of fungi per sample of a particular host or mangrove is a prerequisite for comparison among the hosts or regions. The mean number of fungi per wood sample in the present study was ranged between 2 and 3. This is relatively higher than other mangroves of Indian Ocean (1-1.5) (least in Maharashtra: Borse, 1988; highest in Seychelles: Hyde and Jones, 1988; and Anadman-Nicobar Islands: Chinnaraj, 1993), Hong Kong, Macau (1.2-1.7) (Vrijmoed *et al*., 1994), South-East Asia (0.9-2.6) (Tan *et al*., 1989; Hyde, 1989a,b,c; 1990; Tan and Leong, 1992; Jones and Agerer, 1992; Jones and Tan, 1987), but is lower than Malaysia (3.3) (Alias and Jones, 2000). The mean number of fungi per wood sample in our study on *Avicennia officinalis* (2.6-2.9), *Bruguiera gymnorrhiza* (2.9-3), *Rhizophora mucronata* (2-2.4) and *Sonneratia caseolaris* (2.4-2.8) is higher than that of similar hosts of other mangroves: *Avicennia alba* (2.2-2.7; Hyde, 1990; Tan *et al*., 1989), *Avicennia lanata* (2.6; Tan *et al*., 1989); *Bruguiera parviflora* (1-2.6; Hyde 1989c; Alias and Jones, 2000); *Rhizophora mucronata* (1.5-2.2; Hyde 1989b,c) *Rhizophora apiculata* (1.5-1.6; Hyde, 1990; Jones and Agerer, 1992) and *Sonneratia alba* (1.8; Hyde, 1990). The species richness in different mangroves and mangrove hosts in the earlier studies is slightly lower than the present study. Possibilities for such difference include: the texture of wood (hard, medium and soft), presence or absence of bark and substratum or host recurrence.

Non-marine and marine fungi

Critical examination of our data revealed that, nearly one-third (31 fungi) out of 91 fungi identified in this study, can be considered as terrestrial fungi (6 ascomycetes, 2 basidiomycetes and 23 anamorphic fungi), while three are aero-aquatic fungi (see Table 2). Some terrestrial fungi are prevalent in the present study particularly during the monsoon season (e.g. *Phaeoisaria clematidis, Sporidesmium* sp. 1, *Stachybotrys oenanthes* and *Zignoella* sp.) and the summer (*Acremonium* sp.) (see Table 2). Sarma and Vittal (2001) have documented 16 terrestrial fungi on woody litter from the mangroves of east coast of India, but none of them were encountered in the present study. Sadaba *et al*. (1995) studied vertical distribution of fungi on standing senescent stems of *Acanthus ilicifolius* and recovered 34 terrestrial out of 44 fungi. In our study, the woody litter of *Acanthus ilicifolius* supported about 25% of terrestrial fungi. The root endophytic fungi of mangrove plant species of the west coast of India consist of marine, terrestrial and freshwater fungi (Ananda and Sridhar, 2002). Roots of *Rhizophora mucronata* showed the highest species richness and diversity of endophytic fungi.

The occurrence and activity of terrestrial, freshwater and aero-aquatic fungi in mangroves may be dependent on the duration and severity of the rainy season which is lengthy and heavy (June-November) in the west coast of India. Low salinity (monsoon, 0-1.05‰) in the west coast mangroves provide congenial conditions for the activities of terrestrial and aero-aquatic fungal propagules entering the mangrove ecosystem in the monsoon seasons. With few exceptions, the terrestrial fungi recorded in mangroves in the present study are not typical of those found in freshwater streams (Cai *et al*., 2002; Ho *et al.*, 2002; Sivichai *et al.*, 2002) and indicates they may be a transient mycota entering the mangrove ecosystem from aerial litter.

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