
Spatial and Temporal Heterogeneity of Macrofungi in the Protected Forests of Southern India

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Pavithra, M. Sridhar, K. R. Greeshma, A. A. and Karun, N. C. (2016). Spatial and temporal heterogeneity of macrofungi in the protected forests of Southern India. *International Journal of Agricultural Technology* 12(1):105-124.

Abstract Macrofungal inventory at fortnightly intervals up to 10 weeks in two protected forests (arboretum and botanical garden) of the Southwestern India during southwest monsoon yielded 53 species belong to 33 genera. A total of 29 (22 genera) and 36 (26 genera) species were recovered in arboretum and botanical garden, respectively. Sporocarp richness was higher in botanical garden than in arboretum (742 vs. 684). Richness of species, genera, sporocarps and diversity attained the highest during 4th wk except for sporocarps in arboretum (2nd wk). The overall Sørensen's similarity was 36.9% between habitats, while between fortnights of habitats ranged from 18.2% (8th wk) to 34.8% (2nd wk). Both habitats were dominated by four species without overlap. The highest number of fungi was obtained on soil in botanical garden (29.3%), woody debris in arboretum (18.5%) and four species occurred on two substrates. Species richness was higher in medium and coarse than in fine woody debris. Among the abiotic factors, depth of leaf litter, soil moisture, soil pH and total phosphorus content of soil were significantly differed between habitats ($P < 0.05$). In arboretum, species richness vs. soil conductivity showed a positive correlation ($R = 0.745$), while species richness vs. soil phosphorus content was negatively correlated ($R = -0.747$). Nearly 43% of macrofungi in this survey have economic value as edible (12 spp.), medicinal (7 spp.) and mycorrhizal (10 spp.). Up to 7 species have dual benefit as edible/medicinal (1 sp.), edible/mycorrhizal (4 spp.) and medicinal/mycorrhizal (2 spp.). Results of this study advocate future prospects of forest management in the Southwestern India in favor of production of macrofungi during southwest monsoon.

Keywords: Abiotic factors, diversity, ectomycorrhizae, edible fungi, host preference, medicinal fungi, substrate preference

Introduction

Macrofungi are capable to flourish in a variety of ecosystems and the global estimate based on plant/macrofungal ratio is ranging from 23,000 to 110,000 species (Mueller *et al.*, 2007). They involve in organic matter decomposition, nutrient cycling, soil fertility, establish mutualistic association

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with several plant species and serve as an important component of stability of an ecosystem (Hawksworth, 1991; Bandala *et al.*, 1997; Deighton, 2003; Schmit, 2005). Macrofungi constitute the most valuable non-timber forest products and considered as high-value resource worldwide (Wang and Hall, 2004). Several macrofungal communities establish in the forest ecosystem rely on the availability of different substrates and macro-/micro-climatic conditions (Kutszegi *et al.*, 2015). Three major functional communities of macrofungi have been identified in the forest ecosystem include: i) wood inhabitants; ii) ectomycorrhizas; iii) saprophytes (Winterhoff, 1992). Majority of studies on macrofungal community have been conducted in the Northern/Western Europe and North America, thus there is a wide gap in our knowledge on macrofungi from other parts of the world (Kutszegi *et al.*, 2015). Moreover, impact of more than two functional groups as well as on the influence of abiotic factors on macrofungi has been rarely investigated (e.g. Humphrey *et al.*, 2000; Sato *et al.*, 2012). Despite studies on richness of macrofungi in forests with varied altitudinal gradient, comparison of macrofungal assemblages between different landscapes are relatively less (Villeneuve *et al.*, 1989; Nantel and Neumann, 1992).

Southwest coast of India enjoys overall three seasons like dry-summer season (February–May), warm rainy season (June–September) and partially cool post-monsoon season (October–January). In view of environmental protection and to propagate vegetation, several coastal areas are protected with native vegetation either traditional (e.g. sacred grove) or with modern (e.g. arboretum and botanical garden) approaches. Besides, Karnataka State forest department showed concern in protecting/propagating the mangrove vegetation along the coast and establishing green wall by cultivation of specific plant species (e.g. *Casuarina*) on the coastal sand dunes to prevent coastal erosion. Many landscapes with scrub jungles are partially or fully converted into monoculture/polyculture commercial plantations. There are a few studies on the macrofungal composition and diversity in southwest coast although some macrofungi are traditionally used as nutritional and medicinal source (e.g. *Amanita* sp., *Astraeus* spp. and *Termitomyces* spp.) (Ghate *et al.*, 2014; Karun and Sridhar, 2014; Ghate and Sridhar, 2015). It is expected that macrofungal species composition drastically varies between monoculture and protected polyculture forests and such evaluation helpful in future to follow and forecast forest management practices in favor of enhancing macrofungal resources. Therefore, the major objective of this paper is to differentiate macrofungal assemblage and diversity in two protected forests (arboretum and botanical garden) established in typical lateritic region in relation to abiotic factors and

comparison with monoculture forests and mangroves for future management perspective.

Materials and methods

Study location

The southwestern region surveyed consist mainly scrub jungles in sloppy lateritic soils and several commercial plantations have been developed (e.g. *Acacia*, *Anacardium*, *Areca*, *Cacao*, *Casuarina*, *Cocos* and *Hevea*). Some forest patches are traditionally protected as sacred groves (called 'Nagabana'). Besides, some forests are protected in by preventing invading plant species especially *Acacia*. Two such protected forests (arboretum and botanical garden) in typical lateritic region have been selected for macrofungal inventory during monsoon season (June–August, 2014).

The arboretum (12°48'N, 74°55'E; 87 m asl) is about 20 years old consisting of several endemic, endangered and near threatened tree species of the Western Ghats. A total of 2000 plants represented by 57 tree species, 23 shrubby/woody climbers and 16 herbs/under shrubs (Shetty and Kaveriappa, 2001). Botanical garden (12°49'N, 74°55'E; 116 m asl) developed about 25 years consisting mainly medicinal plant species along with native tree species (*Borassus flabellifer*, *Careya arborea*, *Caryota urens*, *Holigarna* sp., *Hopea ponga*, *Macaranga peltata*, *Sapium insigne*, *Syzygium cumini*, *Tamarindus indica* and *Terminalia paniculata*). Noteworthy medicinal plant species include three trees (*Butea monosperma*, *Saraca asoca* and *Vateria indica*), two shrubs (*Calycopteris floribunda* and *Rauvolfia serpentina*) and a climber (*Tinospora cordifolia*).

Survey

Macrofungal survey was performed at fortnightly intervals on the onset of southwest monsoon in five occasions (June–August, 2014). On each fortnight 50 m × 50 m quadrat was randomly selected to screen sporocarps. Morphological features of each species were assessed on sampling and samples were transferred to sterile polythene bags for further laboratory examination and preservation. Field photographs were taken by zoom camera (Sony DSC-HX100V and Nikon D40) and Nikon microscope (YS100, Japan) was used to assess micromorphological features. Each species was identified using different diagnostic keys (Pegler, 1990; Jordan, 2004; Phillips, 2006; Cannon and Kirk, 2007; Mohanan, 2011; Buczacki, 2012; Tibuhwa, 2012; Karun and Sridhar,

2013). Macrofungi were blotted and transferred to a preservative (mixture of water-ethanol-formaldehyde: 14:5:1) and deposited in the mycological herbarium of the Department of Biosciences.

Abiotic factors

Abiotic features of air, leaf litter and soil were determined in four representative spots in each quadrat. Temperature of air (in shade), leaf litter and soil (at about 5–10 cm depth) was measured using mercury thermometer (accuracy $\pm 0.28^{\circ}\text{C}$, Model # 17876; N.S. Dimple Thermometers, New Delhi, India). Air humidity was assessed by Digital Thermohygrometer (accuracy, $\pm 1\%$, Model # TM-1; Mumbai, India). Leaf litter depth was measured using vernier scale. To determine pH and electrical conductivity, soil samples were diluted with distilled water (1:2.5 v/v) followed assessment by water analysis kit (Model # 304; Systronics, Ahmedabad, India). Soil moisture was determined gravimetrically, soil organic carbon (Walkley and Black's rapid titration method) and soil total nitrogen (macro-Kjeldahl method) were determined based on the methods by Jackson (1973). Soil total phosphorus was estimated based on vanadomolybdophosphoric acid method (AOAC, 1990). The C/N ratio was determined.

Data analysis

Number of sporocarps per quadrat (NSQ) in each fortnight was recorded. Mean sporocarps per quadrat (MSQ) for five samplings and relative abundance (RA%) of sporocarp were calculated. Shannon's diversity (Magurran 1988) and Pielou's equitability (Pielou 1975) of macrofungal population for each fortnight were determined. Sørensen's similarity (%) of macrofungal population between habitats and between fortnights of habitats was calculated based on Chao *et al.* (2005). Statistica Version # 8 (StatSoft Inc. 2008) was followed to determine differences in abiotic factors between habitats. Pearson correlation (two-tailed and confidence intervals, 95%) (SPSS 16.0: www.spss.com) was used to find out relationship between richness of species and sporocarp of macrofungi against eleven abiotic factors.

Results

Species composition

Fortnightly survey up to 2.5 months in two protected forests during southwest monsoon yielded 53 macrofungi (33 genera) belongs to different groups like agarics, club fungi, coral fungi, cup fungi, earthstars, globose/stud-like, jelly fungi, polypores and puffballs (Table 1; Fig. 1–11). Overall, the botanical garden possess the highest of 36 species (26 genera) than in arboretum (29 species (22 genera) (Fig. 12). Number of species as well as genera per quadrat in botanical garden was not significantly higher than arboretum ($P > 0.05$). The total number of sporocarps was also higher in botanical garden than in arboretum (742 vs. 684), but their quantity per quadrat did not vary significantly ($P > 0.05$). Although the diversity and evenness were higher in arboretum than in botanical garden they were not significantly differed ($P > 0.05$).

The richness of species and genera in both forests was highest during the second fortnight followed by a steep decline in third fortnight with gradual decline thereafter (Fig. 12). The total sporocarp was highest during first week in arboretum followed by gradual decline. In botanical garden, sporocarps attained a peak in second fortnight and sharply declined in third fortnight. As seen in richness of species and genera, the diversity also attained a peak in second fortnight. The Sørensen's similarity of macrofungi between the forests was 36.9%. Comparison of samplings between forests showed the highest similarity during the second fortnight (34.8%) and it was least during fourth fortnight (18.2%).

Among the 53 macrofungi, 12 species were common to both forests (*Amanita angustilamellata*, *Auricularia* sp., *Clathrus delicatus*, *Crepidotus* sp. 1, *Entoloma serrulatum*, *Geastrum triplex*, *Hexagonia tenuis*, *Marasmius spegazzinii*, *Mycena* sp., *Scleroderma verrucosum*, *Tetrapyrgos nigripes* and *Xylaria hypoxylon*). The most dominant fungus in arboretum was *Marasmius guyanensis* (21.6%) followed by *T. nigripes*, *Collybia aurea* and *G. triplex* (10.7–16.4%). In botanical garden, *Termitomyces microcarpus* showed dominance (21.3%) by followed by *Marasmius* sp. 1, *C. delicatus* and *Nectria cinnabarina* (11.2–16.1%). Although *C. delicatus*, *G. triplex* and *T. nigripes* were common to both forests, they were dominant only in one of the forests.

Table 1. Macrofungal assemblage in arboretum and botanical garden (*, common to both habitats; **, Wood: C, coarse, F, fine, M, medium; ***, Economic value based on traditional knowledge).

Taxon	Number of sporocarps/ quadrat (50 × 50 m) in two-week intervals (NSQ)					Mean Sporo- carps/ quadr at (MSQ)	Relati ve Abund ance (RA%)	Substrate Preferenc e**	Economi c value***
	2	4	6	8	10				
Arboretum									
<i>Marasmius guyanensis</i> Mont. (Fig. 4)	95	50	-	-	-	29.0	21.6	Leaf	-
* <i>Tetrapyrgos nigripes</i> (Fr.) E. Horak	72	22	-	-	15	21.8	16.4	Leaf/ Wood (F)	-
<i>Collybia aurea</i> (Beeli) Pegler	-	-	56	34	-	18.0	13.5	Wood C)	Edible
* <i>Geastrum triplex</i> Jungh. (Fig. 2, 3)	-	-	9	52	10	14.2	10.7	Soil	Medicina l & Mycorrhizal
<i>Marasmius rotula</i> (Scop.) Fr. (Fig. 5)	55	-	-	-	-	11.0	8.3	Leaf	-
* <i>Marasmius spgazzinii</i> (Kuntze) Sacc. & P. Syd. (Fig. 6)	2	-	-	32	-	6.8	5.1	Leaf	-
<i>Ramaria pallida</i> Maire	-	-	9	11	11	6.2	4.7	Soil	-
* <i>Clathrus delicatus</i> Berk. & Broome	-	23	-	-	-	4.6	3.5	Wood (F, M) & Bark (live)	-
<i>Marasmius</i> sp. 2	-	22	-	-	-	4.4	3.3	Leaf	-
* <i>Amanita angustilamellata</i> (Hohn.) Boedijn	1	-	8	2	4	3.0	2.3	Soil	Mycorrhizal
* <i>Auricularia</i> sp.	-	12	-	-	-	2.4	1.8	Wood (M) & Bark	Edible
* <i>Crepidotus</i> sp. 1	-	12	-	-	-	2.4	1.8	Wood M) & Bark	-
* <i>Scleroderma verrucosum</i>	8	-	-	-	-	1.6	1.2	Soil	Medicina l &

(Bull.) Pers.										Mycorrhizal Medicinal
<i>Ganoderma lucidum</i> (Curtis) P. Karst. (Fig. 1)	7	-	-	-	-	1.4	1.1	Wood (C)		
<i>Marasmius</i> sp. 1	7	-	-	-	-	1.4	1.1	Wood (F)		
* <i>Hexagonia tenuis</i> Speg.	6	-	-	-	-	1.2	0.9	Wood (M)		
<i>Marasmius kisangensis</i> Singer	6	-	-	-	-	1.2	0.9	Leaf		
* <i>Mycena</i> sp.	-	6	-	-	-	1.2	0.9	Leaf		
<i>Entoloma</i> sp. 2	-	5	-	-	-	1.0	0.8	Soil		
<i>Pleurotus djamor</i> (Rumph. ex Fr.) Boedijn (Fig. 7)	-	5	-	-	-	1.0	0.8	Wood (M)		Edible
<i>Tremella reticulata</i> (Berk.) Farl.	-	3	-	-	-	0.6	0.5	Wood (C)		Edible
<i>Entoloma</i> sp. 1	-	2	-	-	-	0.4	0.3	Soil		
<i>Lentinus</i> sp.	-	2	-	-	-	0.4	0.3	Wood (C)		
<i>Polyporus dictyopus</i> Mont.	2	-	-	-	-	0.4	0.3	Wood (C)		
* <i>Xylaria hypoxylon</i> (L.) Grev. (Fig. 11)	-	2	-	-	-	0.4	0.3	Soil		Medicinal
* <i>Entoloma serrulatum</i> (Fr.) Hesler	-	1	-	-	-	0.2	0.2	Soil		
<i>Lycoperdon utrifforme</i> Bull.	-	1	-	-	-	0.2	0.2	Soil		Edible & Mycorrhizal
<i>Royoporus spathulatus</i> (Jungh.) A.B. De	1	-	-	-	-	0.2	0.2	Wood (M)		
<i>Russula</i> sp.	1	-	-	-	-	0.2	0.2	Soil		Edible & Mycorrhizal
Botanical garden										
<i>Termitomyces microcarpus</i> (Berk. & Broome) R. Heim (Fig. 10)	-	-	-	-	155	31.0	21.7	Termite mound		Edible & Medicinal

<i>Marasmius</i> sp. 1	-	115	-	-	-	23.0	16.1	Leaf	-
<i>*Clathrus delicatus</i> Berk. & Broome	-	85	-	-	-	17.0	11.9	Wood (S & M) & Bark (live)	-
<i>Nectria cinnabarina</i> (Tode) Fr.	-	80	-	-	-	16.0	11.2	Wood (M)	-
<i>Xylaria</i> sp.	68	-	-	-	-	13.6	9.5	Wood (C)	Medicinal
<i>*Mycena</i> sp.	-	35	-	-	-	7.0	4.9	Leaf	-
<i>*Marasmius spetzianii</i> (Kuntze) Sacc. & P. Syd. (Fig. 6)	-	25	-	-	-	5.0	3.5	Leaf	-
<i>*Entoloma serrulatum</i> (Fr.) Hesler	-	12	1	8	1	4.4	3.1	Soil	-
<i>Dacryopinax spathularia</i> (Schwein.) G.W. Martin	-	19	-	-	-	3.8	2.7	Wood (C)	Edible
<i>*Tetrapyrgos nigripes</i> (Fr.) E. Horak	7	8	-	-	-	3.0	2.1	Leaf & Wood (F)	-
<i>*Geastrum triplex</i> Jungh. (Fig. 2, 3)	-	-	1	-	11	2.4	1.7	Soil	Medicinal & Mycorrhizal
<i>Marasmius</i> sp. 2	-	12	-	-	-	2.4	1.7	Leaf	-
<i>Collybia</i> sp.	-	10	-	-	-	2.0	1.4	Leaf	-
<i>Entoloma</i> sp. 1	-	9	-	-	-	1.8	1.3	Soil	-
<i>Hygrocybe astatogala</i> (R. Heim) Heinem.	-	9	-	-	-	1.8	1.3	Soil	Mycorrhizal
<i>Russula adusta</i> (Pers.) Fr. (Fig. 8)	7	-	-	-	-	1.4	1.0	Soil	Edible & Mycorrhizal
<i>*Scleroderma verrucosum</i> (Bull.) Pers.	5	2	-	-	-	1.4	1.0	Soil	Medicinal & Mycorrhizal
<i>Lepiota echinella</i> Quél. & G.E. Bernard	-	6	-	-	-	1.2	0.8	Soil	-
<i>Lycoperdon lividum</i> Pers.	6	-	-	-	-	1.2	0.8	Soil	Medicinal
<i>Lenzites</i>	1	4	-	-	-	1.0	0.7	Wood (C)	-

<i>vespacea</i> (Pers.) Pat.										
<i>Crepidotus</i> sp. 2	-	4	-	-	-	0.8	0.6	Wood (F)	-	
<i>Geastrum</i> sp.	-	-	-	4	-	0.8	0.6	Soil	Mycorrhizal	
<i>Lepiota</i> sp.	-	3	1	-	-	0.8	0.6	Soil	-	
<i>Cookeina indica</i> Pfister & R. Kaushal	-	-	3	-	-	0.6	0.4	Wood (M)	-	
<i>Entoloma</i> sp. 2	-	3	-	-	-	0.6	0.4	Soil	-	
* <i>Hexagonia tenuis</i> Speg.	3	-	-	-	-	0.6	0.4	Wood (M)	-	
<i>Microporus xanthopus</i> (Fr.) Kuntze	3	-	-	-	-	0.6	0.4	Wood (C)	Decorative	
<i>Russula atropurpurea</i> Peck (Fig. 9)	-	-	1	1	1	0.6	0.4	Soil	Edible & Mycorrhizal	
* <i>Xylaria hypoxylon</i> (L.) Grev. (Fig. 11)	3	-	-	-	-	0.6	0.4	Soil	Medicinal	
* <i>Amanita angustilamellata</i> (Hohn.) Boedijn	-	-	-	2	-	0.4	0.3	Soil	Mycorrhizal	
<i>Coprinus plicatilis</i> (Curtis) Fr.	2	-	-	-	-	0.4	0.3	Soil	Edible	
<i>Lepista</i> sp.	-	-	2	-	-	0.4	0.3	Soil	Edible	
* <i>Auricularia</i> sp.	-	1	-	-	-	0.2	0.1	Wood (M)	Edible	
* <i>Crepidotus</i> sp. 1	-	1	-	-	-	0.2	0.1	Wood (F)	-	
<i>Entoloma</i> sp. 3	-	-	-	1	-	0.2	0.1	Soil	-	
<i>Leucoagaricus rubrotinctus</i> (Peck) Singer	-	-	-	1	-	0.2	0.1	Soil	Mycorrhizal	



Figure 1-11. Representative macrofungi found in arboretum and botanical garden: *Ganoderma lucidum* (1); *Geastrum triplex* immature (2) and mature (3); *Marasmius guyanensis* (inset, ventral view) (4); *Marasmius rotula* (inset, ventral view) (5); *Marasmius spegazzinii* (inset, ventral view) (6); *Pleurotus djamor* (inset, ventral view) (7); *Russula adusta* (arrows: roots at the base of stipe; inset, top view) (8); *Russula atropurpurea* (inset, ventral view) (9); *Termitomyces microcarpus* (inset, ventral view) (10); *Xylaria hypoxylon* (inset, top view) (11) (Bars = 1 cm).

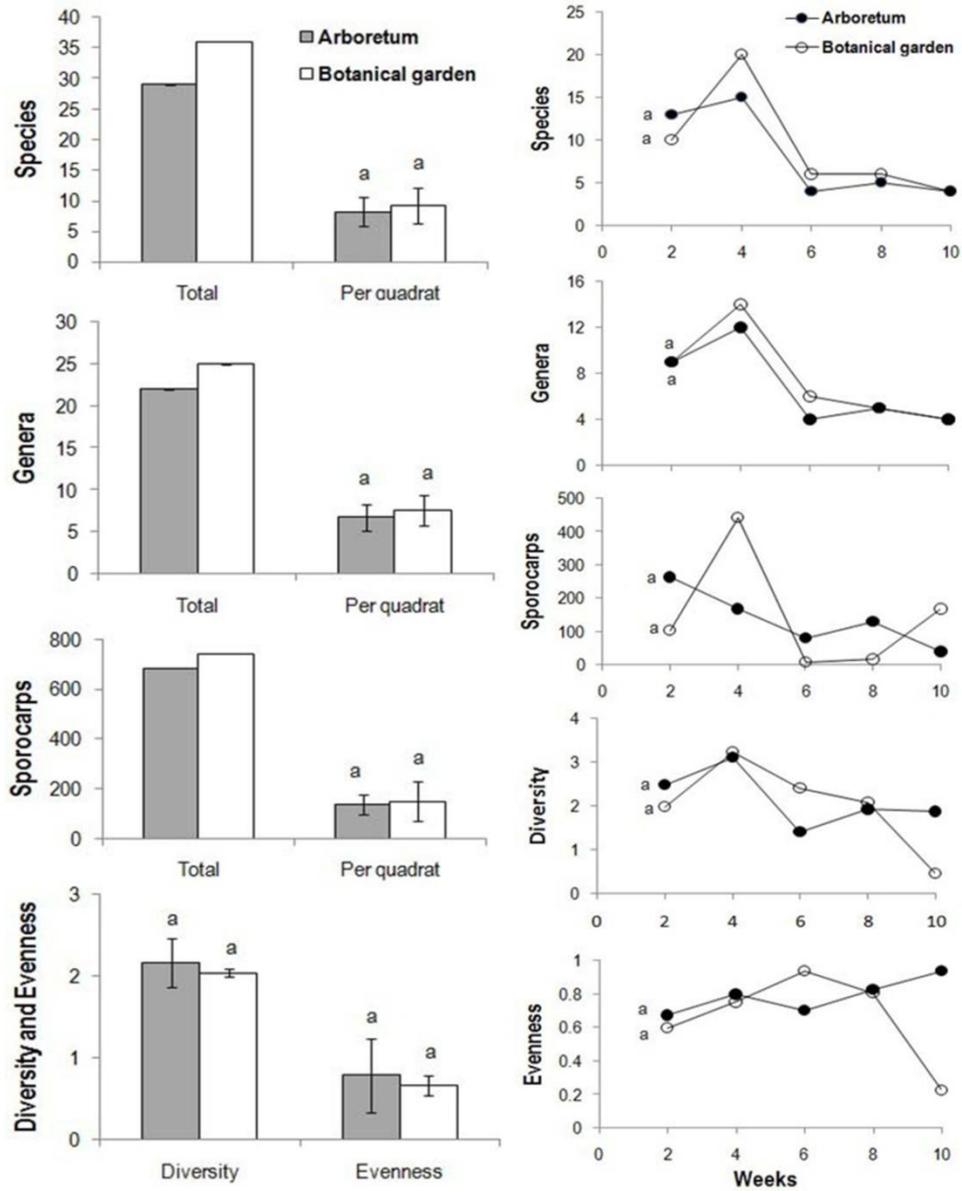


Figure 12. Total species, genera, sporocarps (with species, genera and sporocarps per quadrat), diversity and evenness of macrofungi in arboretum and botanical garden (n = 5, mean ± SE) (bars with same alphabet are not significantly differed: $P > 0.05$); Fluctuation in number of species, genera, sporocarps, diversity and evenness of macrofungi during fortnights in arboretum and botanical garden (lines with same alphabet are not significantly differed: $P > 0.05$).

Abiotic factors

The air temperature and humidity did not vary significantly between forests (Table 2). There was also no significant difference in leaf litter temperature between the forests, but leaf litter depth was significantly higher in botanical garden than in arboretum (4.3 vs. 3.9 cm; $P < 0.05$). The soil temperature, conductivity, organic carbon, total nitrogen and C/N ratio were not differed significantly between forests. But, soil moisture (30.4 vs. 23.4%; $P < 0.01$) and total phosphorus content (0.14 vs. 0.07 mg/g; $P < 0.01$) were significantly higher in the arboretum than botanical garden, while it was opposite for soil pH (5.8 vs. 6.4; $P < 0.05$). Pearson correlation between species richness and abiotic factors (air, leaf litter and soil) resulted in positive correlation between species richness and soil conductivity in arboretum ($R = 0.745$; $P = 0.0135$), while negative correlation between species richness and soil phosphorus content ($R = -0.747$; $P = 0.0130$).

Table 2. Abiotic features in arboretum and botanical garden surveyed for macrofungi (mean, $n = 20 \pm$ SD) (values across the column with different letters are significantly differed, t -test: *, $P < 0.05$; **, $P < 0.01$).

	Arboretum	Botanical garden
Air		
Temperature (°C)	27.8±1.1 ^a	27.6±1.5 ^a
Humidity (%)	81.3±9.3 ^a	82.7±8.3 ^a
Leaf litter		
Temperature (°C)	26.2±0.6 ^a	26.1±1.6 ^a
Depth (cm)	3.9±0.5 ^a	4.3±0.9 ^{b*}
Soil		
Temperature (°C)	27.7±0.7 ^a	25.9±1.4 ^a
Moisture (%)	30.4±5.8 ^a	23.4±4.8 ^{b**}
pH	5.8±0.8 ^a	6.4±0.7 ^{b*}
Conductivity (mS/cm)	10.0±0.8 ^a	7.9±0.9 ^a
Organic carbon (%)	3.6±0.9 ^a	3.3±0.9 ^a
Total nitrogen (%)	1.0±0.2 ^a	1.0±0.2 ^a
C/N ratio	3.7±0.9 ^a	3.5±1.1 ^a
Total phosphorus (mg/g)	0.14±0.04 ^a	0.07±0.01 ^{b**}

Substrate preference

Macrofungi were grown mainly on three substrates such as leaf litter, soil and woody litter (Fig. 13). The highest number of fungi was recovered on soil in botanical garden (29.3%), while on woody debris in arboretum (18.5%). In both forests, leaf preferring fungi were lower (9.2–10.8%) compared to soil

(15.4–29.3%) and wood (16.9–18.5%) preferring fungi. Some fungi grew throughout the leaf litter surface (e.g. *Marasmius guyanensis*, *M. spgazzinii*, *Marasmius* sp. 1 and sp. 2), some preferred midribs as well as veins (e.g. *Tetrapyrgos nigripes*, *Marasmius rotula*, *Marasmius* sp. 2 and *Mycena* sp.) and *Marasmius kisangensis* preferred only the midribs. Majority of macrofungi preferred to grow on lateritic soil, some grew on soil rich in decaying leaf litter (e.g. *Geastrum triplex*, *Marasmius rotula*, *Leipota echinella* and *Russula adusta*), some on soil rich in pebbles (e.g. *Lepista* sp. and *Leucoagaricus rubrotinctus*) and *Termitomyces microcarpus* on termite mound. Fine wood (twigs) attracted least number of fungi in both the forests (8.7%). In the arboretum, medium as well as coarse wood possess highest fungi (21.8%), while in the botanical garden medium wood consists of highest fungi (21.8%). Some macrofungi preferred more than one substrate, for example *Auricularia* sp. grown on medium wood and dead bark; *Crepidotus* sp. grown on fine/medium wood and dead bark; *Clathrus delicatus* grown on fine/medium wood and live bark; *T. nigripes* grown on leaf litter as well as twigs.

Noteworthy macrofungi

This survey yielded up to 23 species (43.4%) economically valuable macrofungi. Twelve species are edible based on traditional knowledge (*Auricularia* sp., *Collybia aurea*, *Coprinus plicatilis*, *Dacryopinax spathularia*, *Lepista* sp., *Lycoperdon utriforme*, *Pleurotus djamor*, *Russula adusta*, *R. atropurpurea*, *Russula* sp., *Termitomyces microcarpus* and *Tremella reticulata*). Seven species possess medicinal importance (*Ganoderma lucidum*, *Geastrum triplex*, *Lycoperdon lividum*, *Scleroderma verrucosum*, *T. microcarpus*, *Xylaria hypoxylon* and *Xylaria* sp.). Ten species are mutualists with tree species as ectomycorrhizae (*Amanita angustilamellata*, *G. triplex*, *Geastrum* sp., *Hygrocybe astatogala*, *Leucoagaricus rubrotinctus*, *L. utriforme*, *R. adusta*, *R. atropurpurea*, *Russula* sp. and *S. verrucosum*).

Many macrofungi have dual advantage as edible and medicinal (*Termitomyces microcarpus*); edible and ectomycorrhizal (*Lycoperdon utriforme*, *Russula adusta*, *R. atropurpurea* and *Russula* sp.); medicinal and mycorrhizal (*Geastrum triplex* and *Scleroderma verrucosum*). Arboretum and botanical garden possess two and one dominant species, respectively: arboretum (edible, *Collybia aurea*; medicinal and ectomycorrhizal, *G. triplex*); botanical garden (edible and medicinal: *Termitomyces microcarpus*).

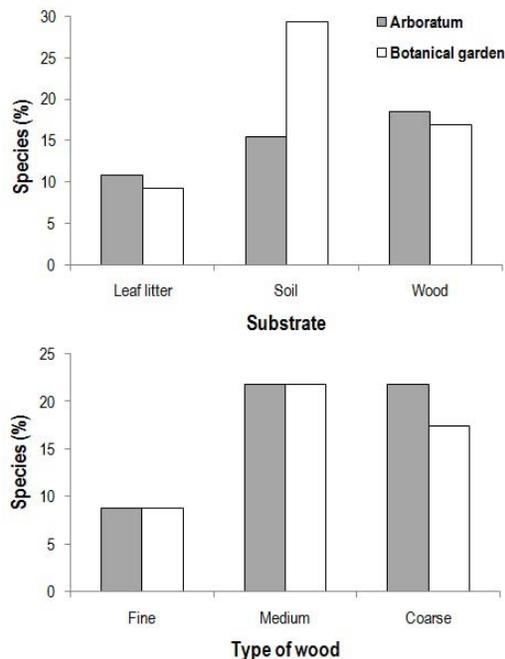


Figure 13. Pattern of substrate preference of macrofungi in arboretum and botanical garden

Some of the macrofungi showed host preference in the forests surveyed, for example *Amanita angustilamellata*, *Geastrum triplex*, *Hygrocybe astatogala*, *Russula atropurpurea* preferred a dicot tree species *Vateria indica* Linn.; *G. triplex* was also preferred a monocot tree species *Caryota urens* L.; *A. angustilamellata* and *Russula adusta* were also showed preference to a dicot tree species *Vateria indica* L.

Discussion

Assemblage in habitats

Assessment of macrofungal assemblage is the first step to understand the species composition, richness, diversity and ability of a specific habitat to support/sustain them. In the Western Ghats and west coast of India, ecological and quantitative studies on macrofungi are scanty (e.g. Natarajan *et al.*, 2005a, 2005b, Brown *et al.*, 2006; Swapna *et al.*, 2008; Ghate *et al.*, 2014; Ghate and Sridhar, 2015). Natarajan *et al.* (2005a) documented ectomycorrhizal complex in dipterocarp forest and agarics in Nilgiri Biosphere Reserve of the Western

Ghats. Among the three forest types studied, sacred groves possess high diversity of macrofungi (Brown *et al.*, 2006). Swapna *et al.* (2008) compared macrofungi in semi-evergreen and moist deciduous forest and found high diversity in semi-evergreen forest. In the southwest coast, interesting macrofungi in mixed forest, monoculture plantations, coastal sand dunes and mangroves (Karun and Sridhar, 2014; Ghate *et al.*, 2014; Ghate and Sridhar, 2015). In almost all studies, protected forests showed diverse macrofungi and corroborating the present study in arboretum and botanical garden. Although both forest types located in the west coast region, the macrofungal assemblage was similar only 36.9% indicating the influence of abiotic factors and type of vegetation in these forests. Among the eight dominant fungi, none of them overlapped between the forests surveyed.

In the Southwest coast of India, studies have been carried out in protected forest (arboretum), natural forests (mangroves) and monoculture plantations (*Anacardium*, *Acacia* and *Areca*) (Karun and Sridhar, 2014; Ghate and Sridhar, 2015). Based on species richness and diversity in these studies as well as our study, protected forests were more productive (29–36 species) compared to monoculture plantations (15–22 species) and mangroves (6–20 species). A variety of edible, medicinal and ectomycorrhizal fungi are represented in the protected forests (arboretum and botanical garden) than monoculture plantations and mangroves. Besides studies conducted on macrofungi in different habitats so far, Southwest coast of India consists of other biomes (e.g. scrub jungles, grasslands, sacred groves, medicinal gardens, mixed plantations, monoculture plantations: *Casuarina* and *Hevea*, estuaries and oceanic/estuarine islands) worth evaluating for macrofungi. Studies conducted revealed that old forests are more productive in macrofungi than recently developed forests. Studies carried out in China showed high species richness and diversity in mixed conifer, broadleaf and deciduous broadleaf forests (Zhang *et al.*, 2010) corroborating with our study in the arboretum and botanical garden.

Impact of abiotic factors

Several biotic and abiotic factors influence successful growth and function of macrofungi in different habitats, vegetation types and forests (Zhang *et al.*, 2010; Kutzegi *et al.*, 2015). Earlier studies monitored macrofungi in the Southwest coast of India on monthly sampling and richness of species and sporocarps attained the highest during the month of June (initial month of southwest monsoon) and gradually decreased (Karun and Sridhar, 2014). In the present study, fortnightly survey resulted peak in richness in

species, sporocarps and diversity in the second fortnight (with exception of sporocarps in the arboretum) indicating the importance of interval of survey and abiotic factors in monitoring macrofungi. Out of 12 abiotic factors assessed in arboretum and botanical garden, only four showed significant difference between forests (leaf litter depth, moisture, pH and total phosphorus content in soil). This was further supported by negative correlation between species richness and soil phosphorus content ($R = -0.747$) and positive correlation between species richness and soil conductivity in arboretum ($R = 0.745$).

Ectomycorrhizal fungal proportions was slightly higher in forests managed for more than 10 years in Nepal than forests managed for short periods (Baral *et al.*, 2015). Two major factors in the forests of Nepal were increase in canopy cover and litter cover on the floor resulted increased species richness. Our study also showed significant increase in the litter depth in botanical garden than arboretum resulting in increased species richness and sporocarp richness corroborating study in Nepal (Baral *et al.*, 2015). In Southwestern China, macrofungal diversity was slightly more in shaded forests than in more exposed/sunny forest slopes (Zhang *et al.*, 2010). Kutszegi *et al.* (2015) interpreted that terricolous saprophytic macrofungal community in the West Hungary was dependent mainly by litter pH gradient based on tree species composition as well as soil/litter properties. Our study also showed acidic pH of soil in arboretum (5.8) as well as in botanical garden (6.4) probably due to tree species composition/litter qualities and with less acidic floor of botanical garden showed high species richness as well as diversity.

Substrate and host preference

Regarding substrate preference in our study, the macrofungi were highest on soil in botanical garden, whereas on woody litter in the arboretum. In mangroves of Southwest India also woody litter especially coarse wood harbored highest macrofungi compared to soil and leaf litter (Ghate and Sridhar, 2015). The present study also emphasized the importance of woody litter and importance of enrichment of soil by leaf as well as woody debris in perpetuation of specific macrofungi.

According to Kutszegi *et al.* (2015), wood-inhabiting macrofungal composition primarily dependent on the tree species composition in the West Hungary. Although ectomycorrhizal fungi have worldwide distribution, their ecology in tropical region is poorly understood (Riviere *et al.*, 2007). Plant species belonging to Dipterocarpace are known to harbor a variety of ectomycorrhizal fungi. In the Western Ghats for example, *Vateria indica* was dominated by *Russula* spp. (Natarajan *et al.*, 2005b). Existence of a few trees of

V. indica in the botanical garden in our study showed occurrence of five ectomycorrhizal fungi (*Amanita angustilamellata*, *Geastrum triplex*, *Hygrocybe astatogala*, *Russula adusta* and *R. atropurpurea*). Natarajan *et al.* (2005b) reported a variety of ectomycorrhizal fungi in other Dipterocarpaceae members like *Dipterocarpus indicus* and *Hopea parviflora*. Interestingly, *Hopea ponga* is a native tree species in the Southwest India also consists of ectomycorrhizal fungus *Astraeus odoratus* (Pavithra *et al.*, 2015). Likewise, *H. parviflora* in the foothill of the Western Ghats yielded edible ectomycorrhizal fungus *Astraeus hygrometricus*. Up to four species in our study were edible as well as ectomycorrhizal and majority of them preferred *V. indica* as host. Such host specificity of macrofungi especially the endangered host species of Dipterocarpaceae indirectly denotes the importance of selection of value-added host plant species for silviculture or to establish protected forests in the coastal region of Southwest India. It also depicts decline in value-added macrofungi due to overharvest of such key plant species in the forests.

Economic value

The present study and earlier studies in arboretum showed more edible, medicinal and ectomycorrhizal fungi than monoculture plantations and mangroves (Karun and Sridhar, 2014; Ghate and Sridhar, 2015). Up to 43% of macrofungi in our survey have economic value as edible, medicinal, and mycorrhizal. Based on the traditional knowledge of local people, several macrofungi are edible and medicinal in our study. Boa (2004) has estimated about 1,069 species of mushrooms used for edible purpose worldwide. According to report of FAO (2004), members *Russula* and *Termitomyces* constitute an important nutritional source in rural India. Thawthong *et al.* (2014) reported that tropical regions are rich in wild macrofungi and those can be cultivated or domesticated. They also indicated several approaches for cultivation of wild saprophytic macrofungi leading to improve the livelihood in rural population and in turn large scale industrial production. Accordingly, *Ganoderma lucidum* and *Pleurotus djmor* occurred in our study can be cultivable. Many more can be cultivable and domesticated based on their nutritional and medicinal attributes. Such efforts help in harvesting desired macrofungi in quantity throughout the year without dependence on season and collection in wild habitats.

Besides, many edible macrofungi also serve as nutraceuticals and some are medicinal due to their valuable bioactive compounds. Some macrofungi serve dual purpose like edible/medicinal; medicinal/ecotmycorrhizal; edible/ecotmycorrhizal. Ectomycorrhizal association enhances the

growth/productivity of host plant species and also enrich the whole soil ecosystem in turn improvement of entire habitat (Smiley *et al.* 1997). According to some investigators, plant diversity serves as a surrogate host in determining the richness and distribution of fungal species, which demands empirical research to strengthen this hypothesis (May, 1991; Hawksworth, 1991, 2001). For example, the richness of ectomycorrhizal plant species in a habitat indirectly predicts richness of ectomycorrhizal species (Heilmann-Clausen and Christensen, 2005; Schmit *et al.*, 2005).

Conclusions

The present study with previous investigations on macrofungi in the Southwest India showed a glaring difference in the macrofungal assemblage and diversity among the vegetation types. Old growth and protected forests are more productive than recent and monoculture forests. Due to less diversity in monoculture forests, polyculture forests may be ideal to the southwest coast to support and harvest value-added macrofungi as additional source of income to the rural-folk. However, practice of forest management especially different types of tree vegetation and organic matter (leaf and woody litter) accumulation on the forest floors plays a significant role in maximizing the benefits from macrofungi. Besides identifying wild beneficial macrofungi, the optimum harvest in wild and cultivation (*in situ* / *ex situ*) reduces pressure on their diversity and perpetuation in their natural habitat.

Acknowledgements

Authors are grateful to Mangalore University for permission to carry out this study in the Department of Biosciences. GAA gratefully acknowledges the award of INSPIRE Fellowship, Department of Science and Technology, New Delhi. KRS acknowledges the UGC-BSR Faculty Fellowship award by the University Grants Commission, New Delhi (award #: F.18-1(64)/2014/BSR). We appreciate Mr. Sudeep D. Ghate, Department of Biosciences for statistical analysis and several plant species have been authentically identified by Mr. Keshava Chandra, Department of Applied Botany.

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(Received: 3 December 2015, accepted: 5 January 2016)