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Spatial and temporal heterogeneity of macrofungi in the protected forests of Southern India

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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 duel 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.

Key words: Abiotic factors, diversity, ectomycorrhizae, edibile 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

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species (Mueller *et al*. 2007). They involve in organic matter decomposition, nutrient cycling, soil fertility, establish mutualistic association 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 relay on the availability of different substrates and macro-/micro-climatic conditions (see 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 ± 0.28°C, Model # 17876; N.S. Dimple Thermometers, New Delhi, India). Air humidity was assessed by Digital Thermohygrometer (accuracy, ± 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 sprorocarps 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 forth 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, Marsmius 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/ quadrat (MSQ)	Relative Abunda-nce (RA%)	Substrate Preference**	Economic value***
	2	4	6	8	10				
Arboretum									
Marasmius guyanensis Mont. (Fig. 4)	95	50	-	-	-	29.0	21.6	Leaf	-
**Tetrapyrgos nigripes* (Fr.) E. Horak	72	22	-	-	15	21.8	16.4	Leaf/ Wood (F)	-
Collybia aurea (Beeli) Pegler	-	-	56	34	-	18.0	13.5	Wood C)	Edible
**Geastrum triplex* Jungh. (Fig. 2, 3)	-	-	9	52	10	14.2	10.7	Soil	Medicinal & Mycorrhizal
Marasmius rotula (Scop.) Fr. (Fig. 5)	55	-	-	-	-	11.0	8.3	Leaf	-
**Marasmius spegazzinii* (Kuntze) Sacc. & P. Syd. (Fig. 6)	2	-	-	32	-	6.8	5.1	Leaf	-
Ramaria pallida Maire	-	-	9	11	11	6.2	4.7	Soil	-
**Clathrus delicatus* Berk. & Broome	-	23	-	-	-	4.6	3.5	Wood (F, M) & Bark (live)	-
Marasmius sp. 2	-	22	-	-	-	4.4	3.3	Leaf	-
**Amanita angustilamellata* (Hohn.) Boedijn	1	-	8	2	4	3.0	2.3	Soil	Mycorrhizal
**Auricularia* sp.	-	12	-	-	-	2.4	1.8	Wood (M) & Bark	Edible
**Crepidotus* sp. 1	-	12	-	-	-	2.4	1.8	Wood M) & Bark	-
**Scleroderma verrucosum* (Bull.) Pers.	8	-	-	-	-	1.6	1.2	Soil	Medicinal & Mycorrhizal
Ganoderma lucidum (Curtis) P. Karst. (Fig. 1)	7	-	-	-	-	1.4	1.1	Wood (C)	Medicinal
Marasmius sp. 1	7	-	-	-	-	1.4	1.1	Wood (F)	-
**Hexagonia*	6	-	-	-	-	1.2	0.9	Wood (M)	-

tenuis Speg.									
Marasmius kisangensis Singer	6	-	-	-	-	1.2	0.9	Leaf	-
**Mycena* sp.	-	6	-	-	-	1.2	0.9	Leaf	-
Entoloma sp. 2	-	5	-	-	-	1.0	0.8	Soil	-
Pleurotus djamor (Rumph. ex Fr.) Boedijn (Fig. 7)	-	5	-	-	-	1.0	0.8	Wood (M)	Edible
Tremella reticulata (Berk.) Farl.	-	3	-	-	-	0.6	0.5	Wood (C)	Edible
Entoloma sp. 1	-	2	-	-	-	0.4	0.3	Soil	-
Lentinus sp.	-	2	-	-	-	0.4	0.3	Wood (C)	-
Polyporus dictyopus Mont.	2	-	-	-	-	0.4	0.3	Wood (C)	-
**Xylaria hypoxylon* (L.) Grev. (Fig. 11)	-	2	-	-	-	0.4	0.3	Soil	Medicinal
**Entoloma serrulatum* (Fr.) Hesler	-	1	-	-	-	0.2	0.2	Soil	-
Lycoperdon utriforme Bull.	-	1	-	-	-	0.2	0.2	Soil	Edible & Mycorrhizal
Royoporus spathulatus (Jungh.) A.B. De	1	-	-	-	-	0.2	0.2	Wood (M)	-
Russula sp.	1	-	-	-	-	0.2	0.2	Soil	Edible & Mycorrhizal
Botanical garden									
Termitomyces microcarpus (Berk. & Broome) R. Heim (Fig. 10)	-	-	-	-	155	31.0	21.7	Termite mound	Edible & Medicinal
Marasmius sp. 1	-	115	-	-	-	23.0	16.1	Leaf	-
**Clathrus delicatus* Berk. & Broome	-	85	-	-	-	17.0	11.9	Wood (S & M) & Bark (live)	-
Nectria cinnabarina (Tode) Fr.	-	80	-	-	-	16.0	11.2	Wood (M)	-
Xylaria sp.	68	-	-	-	-	13.6	9.5	Wood (C)	Medicinal
**Mycena* sp.	-	35	-	-	-	7.0	4.9	Leaf	-
**Marasmius spegazzinii* (Kuntze) Sacc. & P. Syd. (Fig. 6)	-	25	-	-	-	5.0	3.5	Leaf	-

**Entoloma serrulatum* (Fr.) Hesler	-	12	1	8	1	4.4	3.1	Soil	-
Dacryopinax spathularia (Schwein.) G.W. Martin	-	19	-	-	-	3.8	2.7	Wood (C)	Edible
**Tetrapyrgos nigripes* (Fr.) E. Horak	7	8	-	-	-	3.0	2.1	Leaf & Wood (F)	-
**Geastrum triplex* Jungh. (Fig. 2, 3)	-	-	1	-	11	2.4	1.7	Soil	Medicinal & Mycorrhizal
Marasmius sp. 2	-	12	-	-	-	2.4	1.7	Leaf	-
Collybia sp.	-	10	-	-	-	2.0	1.4	Leaf	-
Entoloma sp. 1	-	9	-	-	-	1.8	1.3	Soil	-
Hygrocybe astatogala (R. Heim) Heinem.	-	9	-	-	-	1.8	1.3	Soil	Mycorrhizal
Russula adusta (Pers.) Fr. (Fig. 8)	7	-	-	-	-	1.4	1.0	Soil	Edible & Mycorrhizal
**Scleroderma verrucosum* (Bull.) Pers.	5	2	-	-	-	1.4	1.0	Soil	Medicinal & Mycorrhizal
Lepiota echinella Quél. & G.E. Bernard	-	6	-	-	-	1.2	0.8	Soil	-
Lycoperdon lividum Pers.	6	-	-	-	-	1.2	0.8	Soil	Medicinal
Lenzites vespacea (Pers.) Pat.	1	4	-	-	-	1.0	0.7	Wood (C)	-
Crepidotus sp. 2	-	4	-	-	-	0.8	0.6	Wood (F)	-
Geastrum sp.	-	-	-	4	-	0.8	0.6	Soil	Mycorrhizal
Lepiota sp.	-	3	1	-	-	0.8	0.6	Soil	-
Cookeina indica Pfister & R. Kaushal	-	-	3	-	-	0.6	0.4	Wood (M)	-
Enteloma sp. 2	-	3	-	-	-	0.6	0.4	Soil	-
**Hexagonia tenuis* Speg.	3	-	-	-	-	0.6	0.4	Wood (M)	-
Microporus xanthopus (Fr.) Kuntze	3	-	-	-	-	0.6	0.4	Wood (C)	Decorative
Russula atropurpurea Peck (Fig. 9)	-	-	1	1	1	0.6	0.4	Soil	Edible & Mycorrhizal
**Xylaria hypoxylon* (L.) Grev. (Fig. 11)	3	-	-	-	-	0.6	0.4	Soil	Medicinal
**Amanita angustilamellat*	-	-	-	2	-	0.4	0.3	Soil	Mycorrhizal

a (Hohn.) Boedijn									
Coprinus plicatilis (Curtis) Fr.	2	-	-	-	-	0.4	0.3	Soil	Edible
Lepista sp.	-	-	2	-	-	0.4	0.3	Soil	Edible
**Auricularia* sp.	-	1	-	-	-	0.2	0.1	Wood (M)	Edible
**Crepidotus* sp. 1	-	1	-	-	-	0.2	0.1	Wood (F)	-
Entoloma sp. 3	-	-	-	1	-	0.2	0.1	Soil	-
Leucoagaricus rubrotinctus (Peck) Singer	-	-	-	1	-	0.2	0.1	Soil	Mycorrhizal

Fig. 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).

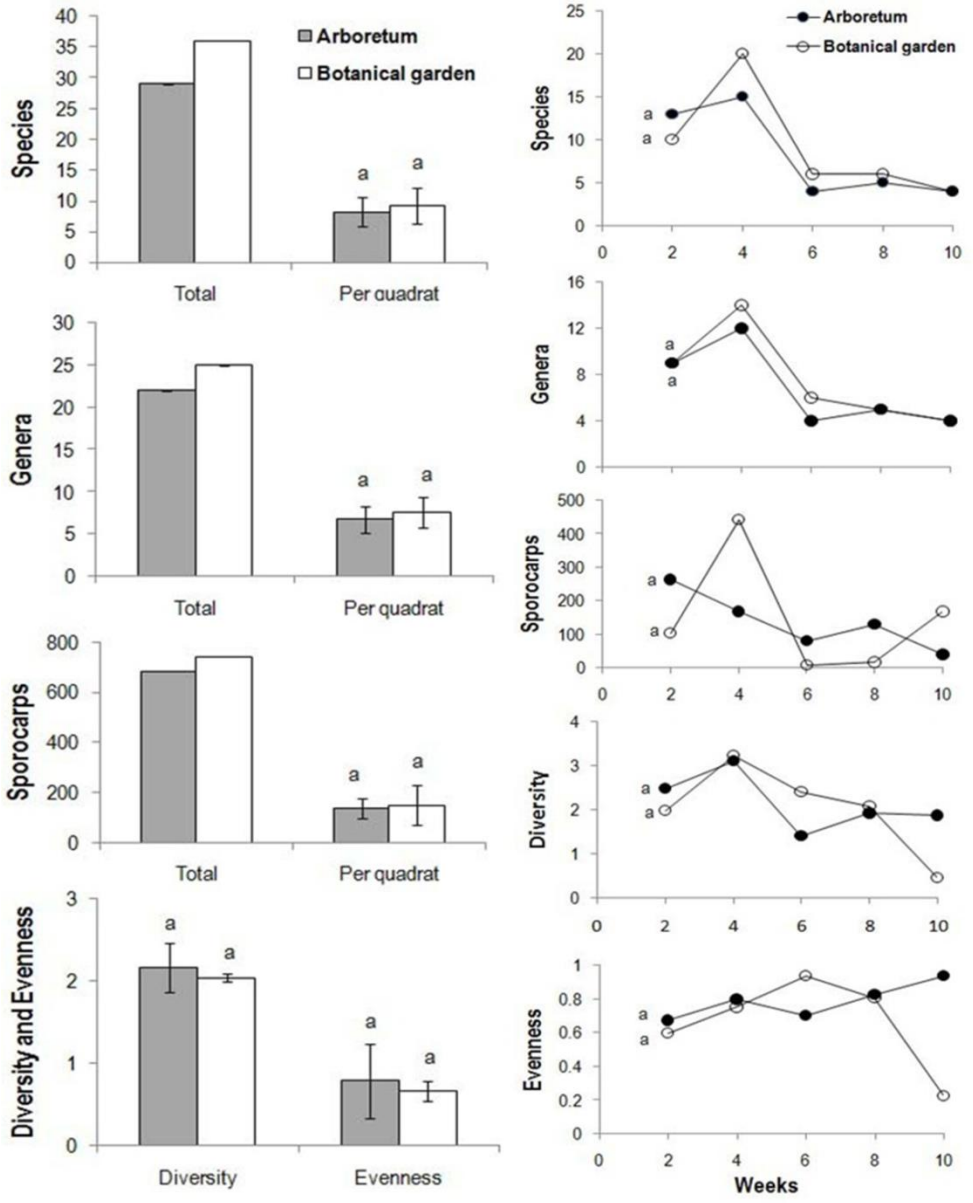

Fig. 12. Total species, genera, sporocarps (with species, genera and sporocarps per quadrat), diversity and evenness of macrofungi in arboretum and botanical garden (n = 5, mean ± SE) (bars with same alphabet are not significantly differed: $P > 0.05$); Fluctuation in number of species, genera, sporocarps,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

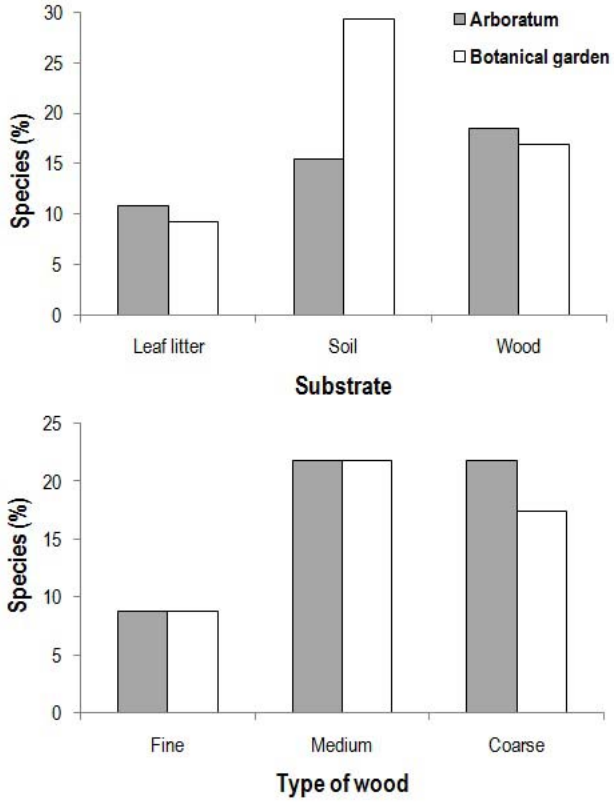

Fig. 13. Pattern of substrate preference of macrofungi in arboretum and botanical garden

Many macrofungi have duel 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*).

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 monocluture 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; Kutszegi *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 ecotomycorrhizal 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 ecotomycorrhizal 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/ectomycorrhial. 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.

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References

AOAC (1990) Official methods of analysis, 15th edition. Association of Official Analytical Chemists, Washington DC

Bandala VM, Montoya L, Chapela IH (1997) Wild edible mushrooms in Mexico: a challenge and opportunity for sustainable development. In: Palm ME, Chapela IH (eds) Mycology in sustainable development: expanding concepts, vanishing borders. Parkway Publication, Boone, NC, pp 76–90

Baral S, Thapa-Magar KB, Karki G, Devkot S, Shrestha BB (2015) Macrofungal diversity in community-managed Sal (*Shorea robusta*) forests in central Nepal. Mycology DOI: 10.1080/21501203.2015.1075232

Boa E (2004) Wild edible fungi: a global overview of their use and importance to people. Non-Wood Forest Products # 17, FAO, Forestry Department, Rome

Brown N, Bhagwat S, Watkinson S (2006) Macrofungal diversity in fragmented and disturbed forests of the Western Ghats of India. J Appl Ecol 43: 11−17

Buczacki S (2012) Collins Fungi Guide. Harper-Collins Publishers, London

Cannon PF, Kirk PM (2007). Fungal families of the world. CAB International, Willingford, Oxfordshire.

Chao A, Chazdon RL, Colwell RK, Shen T-J (2005) A new statistical approach for assessing similarity of species composition with incidence and abundance data. Ecol Lett 8:148–159

Deighton J (2003) Fungi in ecosystem processes. Marcel Dekker, New York

FAO (2004) Non wood forest products, wild edible fungi: A global overview of their use and importance. Boa E (ed) FAO Publications, Rome

Ghate SD, Sridhar KR (2015) Contribution to the knowledge on macrofungi in mangroves of the southwest India. Plant Biosys Doi: 10.1080/11263504.2014.994578

Ghate SD, Sridhar KR, Karun NC (2014) Macrofungi on the coastal sand dunes of south-western India. Mycosphere 5:144–151

Hawksworth DL (1991) The fungal dimension of biodiversity: magnitude, significance, and conservation. Mycol Res 95:641–655

Hawksworth DL (2001) The magnitude of fungal diversity: the 1.5 million species estimate revisited. Mycol Res 105:1422–1432

Heilmann-Clausen J, Christensen M (2005) Wood-inhabiting macrofungi in Danish beech-forests conflicting diversity patterns and their implications in a conservation perspective. Biol Conserv 122:633–642

Humphrey JW, Newton AC, Peace AJ, Holden E (2000) The importance of conifer plantations in northern Britain as a habitat for native fungi. Biological Conservation 96, 241–252

Jackson ML (1973) Soil chemical analysis. Prentice Hall of India, New Delhi

Jordan M (2004) The Encyclopedia of Fungi of Britain and Europe. Francis Lincoln Publishers Ltd, London

Karun NC, Sridhar KR (2013) On the occurrence and distribution of *Termitomyces* (Basidiomycota, Agaricales) in the Western Ghats and on the west coast of India. Czech Mycol 65:233−254

Karun NC, Sridhar KR (2014) A preliminary study on macrofungal diversity in an arboretum and three plantations of the southwest coast of India. Cur Res Environ Appl Mycol 4:173–187

Kutszegi G, Siller I, Dima B, Takács K, Mernyi Z, Varga T, Turcsányi G, Bidlo A, Ódor P (2015) Drivers of macrofungal species composition in temperate forests, West Hungary: functional groups compared. Fungal Ecol 17:69−83

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

May RM (1991) A fondness for fungi. Nature 352:475–476

Mohanan C (2011) Macrofungi of Kerala. Kerala, Handbook # 27. Kerala Forest Research Institute, Peechi, India

Mueller GM, Schmit JP, Leacock PR, Buyck B, Cifuentes J, Desjardin DE, Halling RE, Hjortstam K, Iturriaga T, Larsson K-H, Lodge DJ, May TW, Minter D, Rajchenberg M, Redhead SA, Ryvarden L, Trappe JM, Walting R, Wu Q (2007) Global diversity and distribution of macrofungi. Biodivers Conserv 16:37−48

Nantel P, Neumann P (1992) Ecology of ectomycorrhizal basidiomycete communities on a local vegetation gradient. Ecology 73:99–117

Natarajan K, Narayanan K, Ravindran C, Kumaresan V (2005a) Biodiversity of agarics from Nilgiri Biosphere Reserve, Western Ghats, India. Curr Sci 88:1890–1893

Natarajan K, Senthilarasu G, Kumaresan V, Riviere T (2005b) Diversity in ectomycorrhizal fungi of a dipterocarp forest in Western Ghats. Curr Sci 88:1893–1895

Pavithra M, Greeshma AA, Karun NC, Sridhar KR (2015) Observations on the *Astraeus* spp. of Southwestern India. Mycosphere 6:421–432

Pegler D. 1990. Kingfisher field guide to the mushrooms and toadstools of Britain and Europe. Kingfisher Publications, London

Phillips R (2006) Mushrooms. Pan Macmillan, London

Pielou FD (1975) Ecological Diversity. Wiley InterScience, New York

Riviere T, Diedhiou AG, Diabate M, Senthilarasu G, Natarajan K, Verheken A, Buyck B, Dreyfus B, Bena G, Ba AM (2007) Genetic diversity of ectomycorrhizal basidiomycetes from African and Indian tropical rain forests. Mycorrhiza 17:415–428

Sato H, Morimoto S, Hattori T (2012) A thirty-year survey reveals that ecosystem function of fungi predicts phenology of mushroom fruiting. PLoS One 7:e49777

Schmit JP (2005) Species richness of tropical wood-inhabiting macrofungi provides support for species energy theory. Mycologia 97:751–761

Schmit JP, Mueller GM, Leacock PR, Mata JL, Wu QX, Huang YG (2005) Assessment of tree species richness as a surrogate for macrofungal species richness. Biol Conserv 121:99–110

Shetty BV, Kaveriappa KM (2001) An arboretum of endemic plants of Western Ghats at Mangalore University Campus, Karnataka, India. Zoos' Print Journal 16, 431–438

Smiley TE, Marx DH, Fraedrich BR (1997) Ectomycorrhizal fungus inoculation of established residential trees. J Arboric 23:113–115

StatSoft (2008) Statistica, version # 8. StatSoft Inc, Oklahoma

Swapna S, Abrar S, Krishnappa M (2008) Diversity of macrofungi in semi-evergreen and moist deciduous forest of Shimoga District, Karnataka, India. J Mycol Pl Pathol 38:21–26

Thawthong A, Karunarathna SC, Thongklang N, Chukeatirote E, Kakumyan P, Chamyuang S, Rizal LM, Mortimer PE, Xu J, Callac P, Hyde KD (2014) Discovering and domesticating wild tropical cultivable mushrooms. Chiang Mai J Sci 41:1−34

Tibuhwa DD (2012) *Termitomyces* species from Tanzania, their cultural properties and unequalled basidiospores. J Biol Life Sci 3:140–159

Villeneuve N, Gradntner MM, Fortin JA (1989) Frequency and diversity of ectomycorrhizal and saprophytic macrofungi in the Laurentide Mountains of Quebec. Can J Bot 67:2616–2629

Wang Y, Hall R (2004) Edible ectomycorrhizal mushrooms: challenges and achievements. Can J Bot 82:1063–1073

Winterhoff W (1992) Fungi in Vegetation Science. Kluwer Academic Press, The Netherlands

Zhang Y, Zhou DQ, Zhao Q, Zhou TX, Hyde KD (2010) Diversity and ecological distribution of macrofungi in the Laojun mountain region, southwestern China. Biodivers Conserv 19:3545–3563

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