Diversity of arbuscular mycorrhizal fungi on the coastal sand dunes of the west coast of India

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We examined the diversity of arbuscular mycorrhizal (AM) fungi associated with the dominant strand plant species, *Ipomoea pes-caprae* of the coastal sand dunes of west coast of India. The study reports the impact of rhizosphere edaphic features and disturbance on the species richness and diversity of AM fungi in 10 geographical locations consisting of moderately disturbed dunes (MDD) and severely disturbed dunes (SDD) during wet and dry seasons. The vegetation cover, AM fungal colonization, species richness and diversity were greater in MDD than in SDD, irrespective of seasons. The AM species richness and spore density of both MDD and SDD were strongly correlated with rhizosphere nitrogen. Among the nine rhizosphere edaphic features, the nitrogen and phosphate showed significant difference between MDD and SDD. Pooled data indicate that *Glomus mosseae* was most dominant, followed by *Glomus dimorphicum*, *Gigaspora gigantea*, *Acaulospora taiwania*, *Glomus fasciculatum* and *Glomus* sp. 27SS. Eleven species scored above 10% frequency on MDD, and it was only three species on SDD. *G. mosseae, G. dimorphicum* and *G. gigantea* were most common in both MDD and SDD. The changes in AM fungal community on these sand dunes are in response to disturbance rather than the reflection on temporal patterns of variation.

THE term 'arbuscular mycorrhiza' (AM) has undergone many nomenclatural changes from 'endomycorrhiza' to 'vesicular-arbuscular mycorrhiza' (VAM). Since the VAM did not resemble, both evolutionarily and functionally, other types of endomycorrhiza which penetrated the root cells, the term 'vesicular-arbuscular mycorrhiza' was preferred[1]. Later it was understood that all VAM which belonged to the order Glomales possess distinguishable features: vesicles, arbuscules and coils[2]. Recently, 'V' in VAM was eliminated since the members of the Gigasporaceae do not form vesicles[3].

AM fungi play a vital role in primary and secondary succession of plant species, especially in low nutrient ecosystems (e.g. coastal sand dunes). Increased nutrient supply, salinity tolerance, reduced abiotic stresses and formation of wind-resistant aggregates are the major benefits derived by the sand dune plant species through AM fungal association[4–6]. Although several surveys have been conducted in temperate and subtropical regions[7], a few were performed from the tropical coast of Hawaiian Islands[8,9], India[10–12] and Singapore[13]. Coastal sand dunes are susceptible for natural as well as human disturbances which affect the dune plant community structure and stability.

Ipomoea pes-caprae (L.) R. Br. (Convolvulaceae) is a dominant and widely distributed stoloniferous creeping sand binder in tropical sand dunes[14]. *I. pes-caprae* was found on the dunes of different magnitudes of disturbance on the west coast of India. Measuring biodiversity helps to understand the ecology of the habitat and to develop the conservation strategies. The present study deals with the colonization, species richness and diversity of AM fungi associated with *I. pes-caprae* in relation to rhizosphere edaphic features in moderately disturbed and severely disturbed sand dunes, during wet and dry seasons, on the west coast of India.

Materials and methods

Study site

The study was conducted on 10 coastal dunes along a 100-km stretch across the west coast of India (Figure 1), during the dry season (March–April) and the wet season (September–October) in 1995. Even though most of the coastal sand dunes are subjected to natural disturbance, the degree of disturbance varies (Table 1). Depending upon the magnitude of disturbance, the 10 coastal sand dunes studied are classified into two categories: moderately disturbed dunes (MDD) and severely disturbed dunes (SDD). The MDD possess moderate to dense vegetation cover and high plant diversity. The natural disturbance includes sea erosion or sand accretion. Besides being sites of recreation, the dunes are the sites for human activities like fishing, boat lodging, harbour operations, sand and shell mining. Encroachment, roads and the granite wall construction have severe influence on the dune vegetation[15]. In spite of natural and human disturbances, *I. pes-caprae* has established on all these locations, but the plant cover decreases with increasing disturbance. Climatic factors are almost uniform along the chosen coastal stretch.

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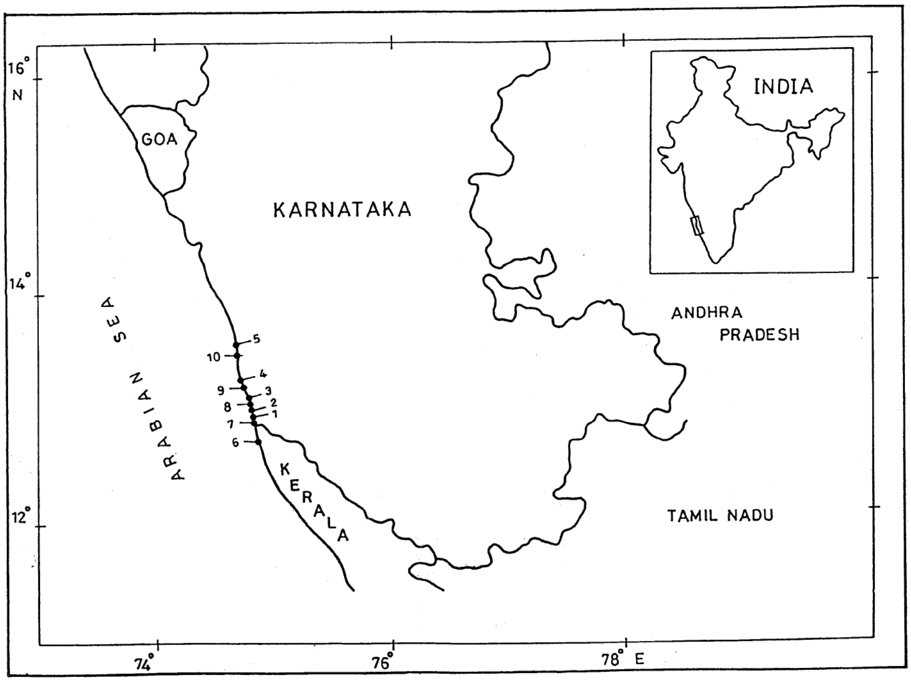

Figure 1. Map showing the moderately disturbed (1–5) and severely disturbed (6–10) coastal sand dune sampling locations along the west coast of India: Uchila (1), Someshwara (2), Bengre (3), Surathkal (4), Malpe (5), Uppala (6), Thalapady (7), Ullal (8), Panambur (9) and Kaup (10).

Table 1. Details of 10 coastal sand dune sites selected to screen AM fungal association with *I. pes-caprae*, on the west coast of India

		Disturbance	
Location	Vegetation	Human	Natural
Moderately disturbed dunes			
Uchila	Profuse	Recreation	Moderate accretion
Someshwara	Profuse	Recreation	Moderate accretion and erosion
Bengre	Moderate	Recreation	Moderate accretion
Surathkal	Moderate	Recreation, sand and shell removal	Moderate accretion and erosion
Malpe	Profuse	Recreation	Moderate erosion
Severely disturbed dunes			
Uppala	Scanty	Encroachment	Heavy accretion
Thalapady	Less	Fishing, boat lodge and road	Moderate erosion
Ullal	Scanty	Encroachment, fishing, boat lodge and sea wall*	Severe erosion
Panambur	Less	Recreation and harbour activities	Less erosion
Kaup	Less	Recreation, encroachment, fishing, boat lodge and sand removal	Severe erosion

*Granite boulder wall constructed to prevent erosion.

Sampling

Five plants at 10–50 m apart were selected for sampling. From each plant, feeder roots of 2 mm diameter were collected in polythene bags. About 300 g of rhizosphere soil sample from the rhizosphere of each plant at a depth of 15–30 cm was collected in polythene bags and stored at 5°C for a couple of weeks before processing.

Rhizosphere edaphic features

Moisture content and pH of rhizosphere soil were determined within 2–3 h of sample collection by drying at 80°C for 24 h. Soil pH was measured after dilution with distilled water (1:1 v/v). The following parameters were analysed according to the methods outlined by Jackson[16]. Organic carbon was detected by Walkley and

Black's rapid titration method as described by Jackson[16]. Total exchangeable calcium, sodium and potassium were detected by flame emission spectrophotometry. The chloride content was detected by titration against silver nitrate with potassium chromate indicator. Total nitrogen was determined by macro-Kjeldahl method. Available phosphorus was detected by Olsen's method.

Colonization and spore density

Colonization of AM fungi was assessed by staining the root pieces in trypan blue[17]. The spore density in 20 g of air-dried rhizosphere soil was assessed by employing floatation–adhesion technique[18]. The AM fungi were identified with the help of standard monographs[3,19–21].

Data analysis

Differences in the nine rhizosphere edaphic features between MDD and SDD were analysed by employing independent samples *t*-test (MICROSTAT, Ecosoft, Inc. 1984). Independent samples *t*-test was also performed to understand the differences in the colonization, spore density and species richness between MDD/SDD and dry/wet season. Variation in AM fungal species richness and spore density in relation to organic carbon, nitrogen and phosphorus was determined by correlation analysis[22] (1-2-3 Access System, Lotus Development Corporation, 1986).

The diversity of AM fungi in 10 locations was assessed based on diversity indices[23]:

Simpson's index: $D' = 1/\sum(pi)^2$,

and

Shannon index: $H' = -\sum(pi \ln pi)$,

where, pi is the proportion of individuals that species i contributes to the total.

The evenness[24] was expressed by:

$$J' = H'/H'_{max},$$

where H'_{max} is the maximum value of diversity for the number of species present.

Paired *t*-test was performed to assess the differences in the diversity between MDD and SDD (MICROSTAT, Ecosoft, Inc. 1984). To compare the species richness among the samples of MDD/SDD and dry/wet season, rarefaction indices were calculated[25]. The expected number of species, $E(s)$, in a random sample of n collections taken from a total population of N collections is calculated using the formula:

Table 2. Rhizosphere edaphic features of *Ipomoea pes-caprae* sand dunes on the west coast of India (n = 5; mean ±SD)

		Moderately disturbed dunes					Severely disturbed dunes				
Edaphic feature	Season	Uchila	Someshwara	Bengre	Surathkal	Malpe	Uppala	Thalapady	Ullal	Panambur	Kaup
Moisture (%)	Dry	0.49 ± 0.04	0.26 ± 0.04	0.63 ± 0.05	0.52 ± 0.07	0.54 ± 0.09	0.59 ± 0.17	0.57 ± 0.12	0.48 ± 0.03	0.47 ± 0.05	0.32 ± 0.03
	Wet	2.6 ± 0.34	3.06 ± 0.62	4.15 ± 0.45	3.74 ± 0.27	2.6 ± 0.34	2.9 ± 0.08	2.77 ± 0.61	3.4 ± 0.28	3.17 ± 0.21	2.6 ± 0.28
pH	Dry	7.45 ± 0.04	6.98 ± 0.1	7.61 ± 0.05	7.74 ± 0.01	7.62 ± 0.02	7.71 ± 0.01	7.68 ± 0.02	7.81 ± 0.09	7.82 ± 0.02	7.82 ± 0.05
	Wet	7.59 ± 0.09	6.94 ± 0.05	7.49 ± 0.04	7.88 ± 0.04	7.67 ± 0.03	7.73 ± 0.03	7.74 ± 0.03	7.64 ± 0.02	7.92 ± 0.02	7.87 ± 0
Organic carbon (%)	Dry	0.02 ± 0.01	0.09 ± 0.13	0.03 ± 0.01	0.098 ± 0	0.03 ± 0	0	0.08 ± 0.07	11.76 ± 7.7	0	0
	Wet	0.04 ± 0	0.03 ± 0.01	0.24 ± 0.06	0.04 ± 0	0.05 ± 0.01	0.03 ± 0.02	0	22.12 ± 3.79	0.11 ± 0.09	0.02 ± 0.01
Calcium (μg g^{-1})	Dry	154.37 ± 4.31	146.71 ± 13	230.4 ± 19.28	167.04 ± 6.87	176.64 ± 15.9	152.83 ± 15.63	75.26 ± 1.88	142.11 ± 17.63	229.25 ± 4.3	215.04 ± 9.64
	Wet	60.29 ± 19.8	138.25 ± 2.87	101.76 ± 7.82	441.98 ± 48	174.34 ± 1.88	145.54 ± 3.72	150.53 ±2.3	112.89 ± 10.75	271.87 ± 15	261.5 ± 34.5
Chloride (μg g^{-1})	Dry	96.73 ± 4.35	76.33 ± 4.35	102.06 ± 10.87	111.16 ± 0.26	113.82 ± 9.91	91.41 ± 5.33	94.96 ± 5.33	110.27 ± 1.9	73.66 ± 2.18	93.19 ± 14.58
	Wet	103.94 ± 6.76	94.07 ± 6.52	83.83 ± 9.85	77.13 ± 9.98	97.62 ± 3.97	86.97 ± 2.18	86.09 ± 2.18	74.55 ± 6.53	88.75 ± 3.97	94.96 ± 6.02
Sodium (μg g^{-1})	Dry	78 ± 1.11	42.43 ± 2.51	141.82 ± 13	93.6 ± 4.6	68.48 ± 9.94	81.24 ± 4.46	75.37 ± 8.95	87.73 ± 1.51	86.91 ± 3.47	70.91 ± 3.33
	Wet	68.88 ± 7.33	38.95 ± 2.02	82.25 ± 4.81	178.69 ± 42.77	74.96 ± 3.07	78.71 ± 9.87	85.7 ± 5.46	72.73 ± 16.71	94.41 ± 6.56	94.41 ± 0.99
Potassium (μg g^{-1})	Dry	7.2 ± 0.3	7.69 ± 1.35	13.16 ± 3.65	8.69 ± 0	17.88 ± 7.56	12.05 ± 1.21	3.23 ± 0.61	12.92 ± 1.14	8.32 ± 0.85	6.83 ± 0.55
	Wet	6.46 ± 0.84	13.75 ± 0.59	10.31 ± 0.74	2.73 ± 0.31	4.22 ± 1.14	7.57 ± 0.25	8.19 ± 0.61	9.69 ± 1.34	8.82 ± 1.14	2.48 ± 0
Nitrogen (μg g^{-1})	Dry	15.96 ± 6.17	35.56 ± 1.12	21.56 ± 0.69	1.4 ± 0.89	27.16 ± 6.95	1.96 ± 0.69	12.04 ± 3.02	11.76 ± 7.7	0	10.92 ± 2.06
	Wet	16.8 ± 2.5	37.52 ± 1.05	35 ± 0	0	33.88 ± 1.37	1.4 ± 0	1.68 ± 1.05	22.12 ± 3.79	0	5.6 ± 3.43
Phosphate (μg g^{-1})	Dry	136 ± 14.97	136 ± 14.97	100 ± 0	128 ± 9.8	120 ± 0	112 ± 9.79	100 ± 0	84 ± 8	96 ± 14.97	124 ± 8
	Wet	75 ± 13.78	44.48 ± 10.04	68 ± 7.48	71 ± 11.15	85 ± 0	80 ± 0	64 ± 8	35 ± 5.43	54 ± 8	64 ± 7.05

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

where n_i is the number of collection of ith species.

Results

Rhizosphere edaphic features

Rhizosphere edaphic features of different locations during dry and wet seasons are given in Table 2. Among the nine edaphic features analysed by employing independent samples t-test, no significant difference was evident between MDD and SDD except for nitrogen and available phosphorus ($P = 0.0111$ and $P = 0.0409$). Although no significant difference was found for organic carbon between MDD and SDD, there was a marked difference in the mean values (0.0670 vs 0.0280%).

Table 3. Colonization, spore density and species richness of AM fungi associated with *I. pes-caprae* on coastal dunes of the west coast of India (mean, n = 5; ± SD)

Location	Season	Colonization (%)	Spores/ 20 g	Species/ sample
Moderately disturbed dunes (MDD)				
Uchila	Dry	20 ± 1.55	3.2 ± 1.16	2.4 ± 0.8
	Wet	82.5 ± 0.95	0	0
Someshwara	Dry	90 ± 1.1	18.4 ± 3.13	7.4 ± 2.42
	Wet	40 ± 0.89	14.4 ± 1.96	6.2 ± 1.12
Bengre	Dry	44 ± 3.21	6.2 ± 3.25	2.4 ± 0.49
	Wet	83.3 ± 0.78	3 ± 1.67	1.8 ± 0.75
Surathkal	Dry	75 ± 3.16	3 ± 1.41	2.2 ± 0.98
	Wet	24.5 ± 2.41	1.8 ± 1.16	0.8 ± 0.4
Malpe	Dry	73.3 ± 1.6	2.6 ± 2.06	1.4 ± 0.8
	Wet	52 ± 2.29	34.6 ± 15.86	7.2 ± 1.33
Severely disturbed dunes (SDD)				
Uppala	Dry	6.7 ± 0.81	0	0
	Wet	25 ± 3.69	0	0
Thalapady	Dry	75 ± 3.16	0.8 ± 0.75	0.8 ± 0.75
	Wet	24.5 ± 2.4	0.6 ± 0.8	0.4 ± 0.49
Ullal	Dry	70.8 ± 3.28	0.4 ± 0.8	0.3 ± 0.47
	Wet	69.7 ± 2.71	3.4 ± 2.15	1.6 ± 0.49
Panambur	Dry	77.8 ± 5.89	0	0
	Wet	17.9 ± 1.77	2.4 ± 1.36	1.8 ± 0.83
Kaup	Dry	73.3 ± 1.6	2.8 ± 2.78	1.2 ± 0.7
	Wet	52 ± 2.29	0	0
Moderately disturbed dunes	Dry and Wet	58.35	8.8	3.18
Severely disturbed dunes	Dry and Wet	48.9	1	0.61
Dry season	MDD and SDD	60.3	3.8	1.8
Wet season	MDD and SDD	46.8	6	2

Colonization, spore density and species richness

Details of colonization, spore density and species richness are given in Table 3. Colonization of AM fungi was greatest (40–90%) at Someshwara, while it was least (6.7–25%) at Uppala. No significant difference was found in colonization between MDD and SDD, so also between dry and wet seasons. The overall colonization pattern differs between MDD (mean: 58.35%) and SDD (mean: 48.9%) or between dry (60.3%) and wet (46.8%) seasons. The spore density was least in SDD compared to MDD. Significant difference ($P = 2.478 \times 10^{-5}$) was noticed in the spore density between MDD and SDD, but there was no significant difference ($P > 0.05$) in the spore densities of dry and wet seasons. The observed spore density was 0.44 and 0.05 g^{-1} in MDD and SDD, respectively, while it was 0.19 and 0.3 g^{-1} in dry and wet seasons, respectively. The number of species recovered per sample was 3.18 and 0.61 between MDD and SDD, respectively, and it was 1.8 and 2 per sample during dry and wet seasons. The number of species was highest at Someshwara (6.3–7.4) followed by Malpe (1.4–7.2), but the samples of Uppala were devoid of AM spores. The spore density (0.81124) and species richness of both MDD and SDD (0.79566) was strongly correlated with rhizosphere nitrogen (c.v., 2-tail, 0.05 = ± 0.62972), but not with organic carbon and phosphorus.

Occurrence of AM fungi

Table 4 provides the frequency of occurrence and relative abundance of AM fungal species in the rhizosphere of *I. pes-caprae* in MDD/SDD and dry/wet seasons. The survey revealed the occurrence of 31 species in MDD, while only seven species in SDD. Except for the genus *Entrophospora*, rest of the five genera were recovered in this survey. Members of the family Glomaceae were dominant (61.3%), followed by Acaulosporaceae and Gigasporaceae (19.35%). Pooled data indicate that *Glomus mosseae* was the most dominant (12–40%) followed by *Glomus dimorphicum* (12–24%), *Gigaspora gigantea* (8–32%), *Acaulospora taiwania* (0–28%), *Glomus fasciculatum* (0–32%) and *Glomus* sp. 27SS (0–32%). Eleven species showed above 10% frequency of occurrence on MDD, and only three species on SDD. *G. mosseae, G. dimorphicum* and *G. gigantea* were most common both on MDD and SDD (> 10%).

Species richness and diversity

Species richness was consistently greater in MDD (6–19) than in SDD (0–5) (Table 5). Significant difference was found in the species richness between MDD and SDD ($P = 1.490 \times 10^{-7}$), but it was not significant be-

Table 4. Frequency of occurrence and relative abundance of AM fungal spores in the rhizosphere of *I. pes-caprae* on the sand dunes of west coast of India

Taxon		Frequency of occurrence (%)*		Relative abundance (%)**	
		MDD	SDD	MDD	SDD
Gigasporaceae					
Gigaspora margarita Becker & Hall	D	16	0	5.36	0
	W	0	0	0	0
G. albida Schenck & Smith	D	4	0	0.59	0
	W	24	0	3.35	0
Scutellospora erythropa (Koske & Walker) Walker & Sanders	D	8	0	1.19	0
	W	12	0	1.12	0
S. calospora (Nicolson & Gerdemann) Walker & Sanders	D	0	0	0	0
	W	12	0	1.12	0
Scutellospora sp. 43SS	D	4	0	0.59	0
	W	0	0	0	0
G. gigantea (Nicolson & Gerdemann) Gerdemann & Trappe	D	20	12	4.17	20
	W	32	8	5.2	9.38
Acaulosporaceae					
Acaulospora denticulata Sieverding & Toro	D	0	0	0	0
	W	8	0	0.74	0
Acaulospora sp. 23KS Gerdemann & Trappe	D	4	0	0.59	0
	W	0	0	0	0
A. nicolsonii Walker, Reed & Sanders	D	16	0	4.76	0
	W	16	0	2.98	0
A. taiwania Hu	D	28	0	10.12	0
	W	16	0	4.46	0
A. spinosa Walker & Trappe	D	8	0	1.79	0
	W	20	4	5.2	3.13
Acaulospora sp. 19DS	D	0	0	0	0
	W	4	0	0.37	0
Glomaceae					
Glomus albidum Wakler & Rhodes	D	28	0	12.5	0
	W	8	0	1.12	0
G. mosseae (Nicolson & Gerdemann) Gerdemann & Trappe	D	28	12	17.26	15
	W	40	20	11.9	31.25
G. aggregatum Schenck & Smith emend. Koske	D	12	0	1.79	0
	W	12	0	2.98	0
G. lacteum Rose & Trappe	D	4	0.8	0.59	0
	W	20	0	4.09	0
G. fasciculatum (Thaxter) Gerdemann & Trappe emend. Walker & Koske	D	16	0	2.38	0
	W	28	0	5.58	0
Glomus sp. 27SS	D	32	0	17.26	0
	W	12	0	2.23	0
G. tortuosum Schenck & Smith	D	8	0	1.19	0
	W	12	16	2.6	25
G. occultum Walker	D	8	0	2.38	0
	W	0	12	0	15.63
G. globiferum Koske & Walker	D	8	0	1.19	0
	W	0	0	0	0
G. microaggregatum Koske, Gemma & Olexia	D	8	0	1.79	0
	W	0	0	0	0
G. deserticola Trappe, Bloss & Menge	D	4	0	0.59	0
	W	8	0	1.49	0
G. dimorphicum Boyetchko & Tewari	D	24	12	4.76	50
	W	20	16	40.89	12.5
G. intraradices Schenck & Smith	D	0	8	0	15
	W	8	4	0.74	3.13
Glomus sp. 02DSU	D	8	0	1.19	0
	W	0	0	0	0
Glomus sp. 07DM	D	0	0	0	0
	W	8	0	1.12	0
Glomus sp. 10DM	D	0	0	0	0
	W	8	0	0.74	0
Glomus constrictum Trappe	D	12	0	4.74	0
	W	0	0	0	0
Sclerocystis sp. 43SN	D	4	0	0.59	0
	W	0	0	0	0
Sclerocystis sp. 22SS	D	4	0	0.59	0
	W	0	0	0	0

MDD, Moderately disturbed dunes; SDD, Severely disturbed dunes; D, Dry; W, Wet season.
*Number of soil samples possessing spores of a particular species (in $n = 25$) divided by total number of samples analysed ($n = 25$) × 100.
**Number of spores of a particular species (in $n = 25$) divided by total number of spores (in $n = 25$) × 100.

tween dry and wet seasons ($P > 0.05$). Except for Malpe, the Simpson's diversity was higher in MDD than in SDD (Table 5). The Shannon diversity was highest in MDD. Paired *t*-test for Simpson's diversity between MDD and SDD revealed higher significant difference ($P = 0.00974$) than in Shannon diversity ($P = 0.0339$). The diversity indices and expected number of species [$E(s)$] were greater for MDD than SDD, irrespective of seasons (Table 5, Figure 2).

Discussion

I. pes-caprae, a pioneer mat-forming creeping strand species, shows wide distribution throughout the tropical beaches of the world[14]. It is well adapted to coastal habitats with disturbance, especially burial, erosion and inundation[14,26,27]. In spite of natural and human disturbances, *I. pes-caprae* is dominant and widely distributed on the dunes of the west coast of India. But the extent of its cover varies depending upon the magnitude of disturbance. This plant also supports the coexistence of many other dune plants[28]. In moderately disturbed or stabilized dunes, the flora associated with *I. pes-caprae* include: *Alysicarpus rugosus* (Willd.) DC., *Canavalia cathartica* Thouras, *Canavalia rosea* (Sw.) DC., *Crotalaria retusa* L., *C. verrucosa* L. and *Cyperus pedunculatus* (R. Br.) Kern.

The AM fungal communities on these tropical dunes have shown high levels of diversity, as measured by

Table 5. Species richness, diversity and evenness of AM fungi associated with *I. pes-caprae* on the sand dunes of the west coast of India

Location/season	Species richness	Diversity index: Simpson	Diversity index: Shannon	Shannon-evenness
Moderately disturbed dunes				
Uchila	6	0.816	2.307	0.893
Someshwara	19	0.871	3.381	0.796
Bengre	7	0.891	2.544	0.906
Surathkal	6	0.808	2.365	0.915
Malpe	12	0.609	2.183	0.609
Mean ± SD	10 ± 5	0.799 ± 0.1	2.556 ± 0.429	0.824 ± 0.116
Severely disturbed dunes				
Uppala	0	0	0	0
Thalapady	2	0.476	0.863	0.863
Ullal	3	0.620	1.378	0.869
Panambur	5	0.758	1.951	0.840
Kaup	3	0.473	1.095	0.691
Mean ± SD	2.6 ± 1.6	0.465 ± 0.255	1.057 ± 0.642	0.653 ± 0.333
Moderately disturbed dunes	31	0.885	3.824	0.772
Severely disturbed dunes	7	0.824	2.534	0.903
Dry season	26	0.910	3.856	0.820
Wet season	22	0.823	3.346	0.750

diversity indices. The reduction in the richness of AM fungal populations or their functional diversity has drastic consequences for the equilibrium of natural plant community structure[29,30]. In the present study, the AM fungal diversity and dune plant diversity/vegetation cover were higher in MDD than in SDD. Drastic difference in the colonization of AM fungi was found between MDD and SDD (58.4 vs 48.9%). In an earlier survey[10] also high AM fungal colonization of *I. pes-caprae* was found (60%) on one of the MDD (Someshwara) of the west coast of India. The spore density showed a drastic reduction in SDD compared to MDD (0.05 vs 0.44 g^{-1}), so also the species richness (0.6 vs 3.2/sample) (Table 3). It has been speculated that the disturbance severely affects the reproduction of AM fungi on these dunes. The impact of disturbance seems to be higher on spore production than on the species richness and root colonization. Changes in the AM fungal community between MDD and SDD reflect its response to disturbance rather than a temporal pattern of variation. These results support the theory of reduction of AM fungal propagation under severe disturbance which affects the natural plant community structure, leading to the ecosystem instability[13,29–31]. Among the MDD, *I. pes-caprae* on Someshwara dunes showed maximum colonization (40–90%), maximum number AM fungal species (6.2–7.4/sample) and second highest value for spore density (0.72–0.92 g^{-1}). This increased AM fungal activity may be attributed to the moderate degree of disturbance and the dune's topographical features of Someshwara, supporting Connell's views of intermediate disturbance hypothesis[32]. The frequency of occurrence of 11 species of AM fungi was in the range of 12–34% on MDD, while on SDD only three species were dominant (10–16%). *G. mosseae, G. dimorphicum* and *G. gigantea* were common to both MDD and SDD.

The AM fungi preferentially associate with particles of decomposing organic matter[33]. Increased hyphal growth was observed with increase in organic matter[34]. The organic matter input to the dunes from the tidal action was prevented by sea wall in some locations of the present study. Removal of accumulated woody debris for fuel and fertilizer also reduces the dune organic matter considerably. These interferences indirectly affect the AM fungal activity that alters the plant community structure on the west coast of India. Among the edaphic features, nitrogen and phosphorus are the major limiting factors in the SDD which may have resulted in poor species richness and diversity of AM fungi.

According to Connell's hypothesis, the highest diversity is maintained at intermediate scales of disturbance[32]. This hypothesis may be applicable to the tropical coastal sand dunes of moderate disturbance as well. It is evident that the MDD possess high AM fungal diversity as well as the plant diversity and vegetation cover[10,28]. The moderate levels of disturbance (erosion and accretion/burial) aid in the dispersal of AM fungal propagules as well as the plant propagules to the new sites. Moderate burial confers several advantages such as escape from surface predators, higher nutrient

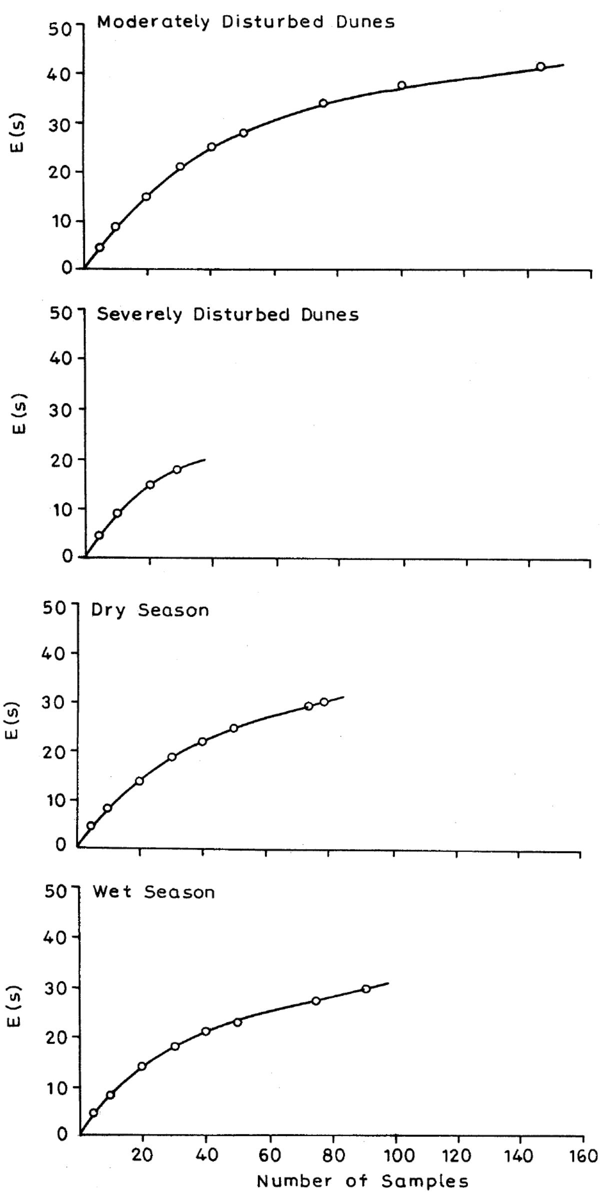

Figure 2. Rarefaction curves on the occurrence of AM fungi [$E(s)$, Expected number of species] in dry/wet season and in moderately disturbed/severely disturbed sand dune locations of the west coast of India.

content, greater access to soil moisture, more space for root growth and insulation of seeds/seedling roots against high temperature/desiccation[35,36]. Burial of seedlings of *I. pes-caprae* also resulted in the elevated biomass[26]. Besides the dispersal of seeds, *I. pes-caprae* regenerate through the vegetative fragments broken off during storms or erosion[14], which will also carry AM fungal mycelia/spores to the new sites for colonization. It has been demonstrated that the vegetative and reproductive structures of AM fungi tolerate considerable exposure to high salinity[37,38]. Plant species are known to be eliminated from the community when the sand burial exceeds their threshold of tolerance[35,36]. The constant and continuous disturbance of dunes might severely affect the seedling establishment as well as the colonization of AM fungi. Among the severe disturbances, heavy sand accretion (Uppala), severe sand erosion (Ullal and Kaup) and human interference (Thalapady and Panambur) are the possible reasons for decreased AM fungal richness/diversity which in turn affect the plant richness/diversity including *I. pes-caprae*. It has been pointed out that the below-ground diversity of AM fungi is one of the major factors contributing to the maintenance of plant biodiversity and to the ecosystem functioning[31]. For instance, the absence of AM fungal propagules in the coastal reclaimed land in Singapore resulted in the failure of colonization of mycorrhizal plant species even after five years of reclamation[13]. Besides natural disturbances, human interference (e.g. pollution, sea wall construction and removal of organic debris) on the dunes may have deleterious effects on the AM fungal diversity, which in turn affect the dune stabilization.

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ACKNOWLEDGEMENTS. We thank Mangalore University for permission to carry out this study. The manuscript has been substantially enriched by the constructive suggestions of the referees.

Received 26 July 2000; revised accepted 9 October 2000