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Structural complexity and tree species composition of mangrove forests of the Andaman Islands, India

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Abstract This study reports the mapping, structural characteristics and distribution of mangrove species of the Andaman Islands. 79 mangrove patches were identified using Thiessen polygons of which, 53 accessible patches were surveyed during 2014–2015. Multiple linear transects were laid at each of the mangrove patches and data pertaining to diameter at breast height, basal area and height were recorded for all mangrove trees within a 10 × 10 m quadrat laid along the transects at 50 m intervals. Altogether, 178 quadrats were laid and 25 mangrove species representing 11 families and 14 genera were recorded. Of the 3073 mangrove plants enumerated in the present study, 96.06% were composed of trees (>4 m height), 1.99% of saplings (>1 m to ≤4 m height) and 1.95% of seedlings (≤1 m height). The number of species per quadrat ranged from 1 to 9 and majority of the quadrats had 2–3 species. Density and basal area of mangrove trees ranged from 1252 ha^{-1} to 2200 ha^{-1} and 30.8 m^2/ha to 59.6 m^2/ha, respectively. High diversity indices (Shannon-Wiener index ranged from 1.65 to 2.24; Simpson index from 0.74 to 0.85 and Pielou's evenness index from 0.66 to 0.84) indicated greater diversity and even dispersion of mangroves in the Islands. The study also revealed that the mangrove forests of Andaman Islands were characterized by a mixed species composition. Most of the sites were represented by different combinations of dominant and co-dominant species, all from the family Rhizophoraceae. The present study highlights the need for conserving the mixed species mangrove forests of Andaman and Nicobar Islands and development of location-specific management plans for biodiversity conservation.

Keywords Andaman Islands · Biodiversity · Conservation · Mangroves · Marine angiosperms

Introduction

Mangrove ecosystem has an important role in ecological and socio-economic terms (Ronnback et al. 2007; Walters et al. 2008; Malik et al. 2015). They offer various livelihood services such as coastal defense, fisheries, carbon storage, tourism, water purification, timber and fuel (Spalding et al. 2014). Further, they protect the integrity of the coast by acting as coastal buffers against cyclones, storms, tsunamis and other waves and tidal damages (Alongi 2008). Research on mangroves has increased exponentially in the last 50 years (Lee et al. 2014). Human interactions with mangroves have also been increased in recent days coupled with natural disasters, which make them more vulnerable to anthropogenic and natural factors. As per recent estimate, mangroves have witnessed an annual loss between 0.16 and 0.39%, globally, due to rapid coastal development (Hamilton and Casey 2016) and mangrove cover has reportedly decreased in countries like China, Myanmar and Philippines, whereas, an increased mangrove cover was reported from India, Australia and New Zealand (Chaudhuri et al. 2015). Degradation and loss of these coastal buffering systems due to climate change and direct human impact negate the coastal protection they provide during extreme events and increase their vulnerability (Ellison 2015). Therefore, it is necessary to manage the

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mangrove forests through the integrated planning of coastal zone management (Yulianda et al. 2014).

India with its vast coastline of 8118 km has rich mangrove diversity and the ecosystem offers livelihood to several thousand people across India. Mangrove forests cover 4740 sq. km area along the Indian coastline of which 617 sq. km occur in the Andaman and Nicobar Islands (FSI 2015). The mangrove cover is larger and more widespread on the east coast of India than the west coast because of its distinctive geomorphological setting (Ragavan et al. 2016a). Andaman and Nicobar Islands (ANI) located in the Bay of Bengal is one of the most vulnerable coasts close to South east Asian countries which is experiencing frequent natural calamities such as earthquake, cyclones, storms, Tsunami etc. Mangroves of Andaman Islands are recognized as the best in the country in terms of density and growth (Dagar et al. 1991). In recent times, mangrove floristics of ANI have been studied by many (Roy 2003; Roy et al., 2009; Goutham-Bharathi et al. 2014; Ragavan et al. 2014; Ragavan et al. 2015a, b), and total of 38 true mangrove species belonging to 13 families and 19 genera have been known from ANI, which account for about 50% of the global true mangrove species (Ragavan et al. 2016b). In India, habitat destruction, over-exploitation, pollution and species introduction are identified as major causes of biodiversity loss (UNEP 2001) and the disturbance created by these factors determine the structural complexity and species composition (Sagar et al. 2003). Until recently, mangroves of the Islands had remained intact, but this situation is now changing (Spalding et al. 2010). Though not subject to human-driven land-use changes and urbanization threats, mangrove cover in the Islands continues to decline quite rapidly (Goutham-Bharathi et al. 2014).

Management of the fast-declining mangrove ecosystem requires a comprehensive understanding of the species composition and structural complexity (Dislich and Pivello 2002). Prior to forest management operations, biodiversity inventories were used to determine the nature and distribution of the species (Sagar et al. 2003). Though floristics and biodiversity of mangroves in the Islands have been well documented, little is known of the vegetation structure of the mangrove forests. The mangroves within the protected areas demarcated as per Wildlife (Protection) Act, 1972 and those within the identified tribal belts in the islands are under stringent regulatory regime. There is a need for developing management plans for conserving the mangroves outside such regulatory areas. Therefore, the present study was intended to examine the structural complexity and tree species composition of the mangrove forests of the Andaman Islands, with special focus on the areas, outside the protected areas. The study provides a comprehensive perspective of the mangroves of Andaman Islands and a framework for ascertaining their conservation significance. This would aid in formulating location-specific action plans as a part of the Island Coastal Zone Management Plans of Andaman Islands, a regulatory requisite under the Island Protection Zone (IPZ), 2011 notification of the Ministry of Environment, Forest and Climate Change, Government of India.

Materials and Methods

Study area

Mangroves in the ANI were mapped using satellite images at the scale of 1:50,000. Mangroves were differentiated from other coastal and as well as terrestrial vegetation based on their tones (red/pale red), texture (smooth), shape (irregular), location (in intertidal area and near high tidal area) and association (in warm waters on mudflat substrate and low energy coast) using satellite data. Mangrove patches lying outside the Marine Protected Areas / Tribal reserve areas were delineated based on the GIS point database using Thiessen polygons as described by Révész et al. (2003), and Biro et al. (2006), such that every polygon corresponding to each point represents a patch. A total of 79 patches were delineated representing the five regions of the Andaman Islands viz., North Andaman (Diglipur and Mayabunder), Middle Andaman (Baratang, Long Island and Rangat), South Andaman (Port Blair Range), Little Andaman (Hut Bay) and Ritchie's Archipelago (Havelock and Neil), of which 53 patches were surveyed and rest of the patches were not accessible (Table 1). Each patch was given a code, "MGR-AN- 01", representing the ecosystem, state and serial number of the patch from north to south, along with a corresponding local name. All the identified contiguous patches are shown in Fig. 1. The spatial extent of mangroves in each of the Island groups is shown in Table 2. The mangrove stands of ANI were classified based on the extent into three viz., small patches (≤ 5 km^2); medium patches (5–10 km^2) and large patches (≥ 10 km^2).

Table 1 Mangrove patches of the Andaman Islands

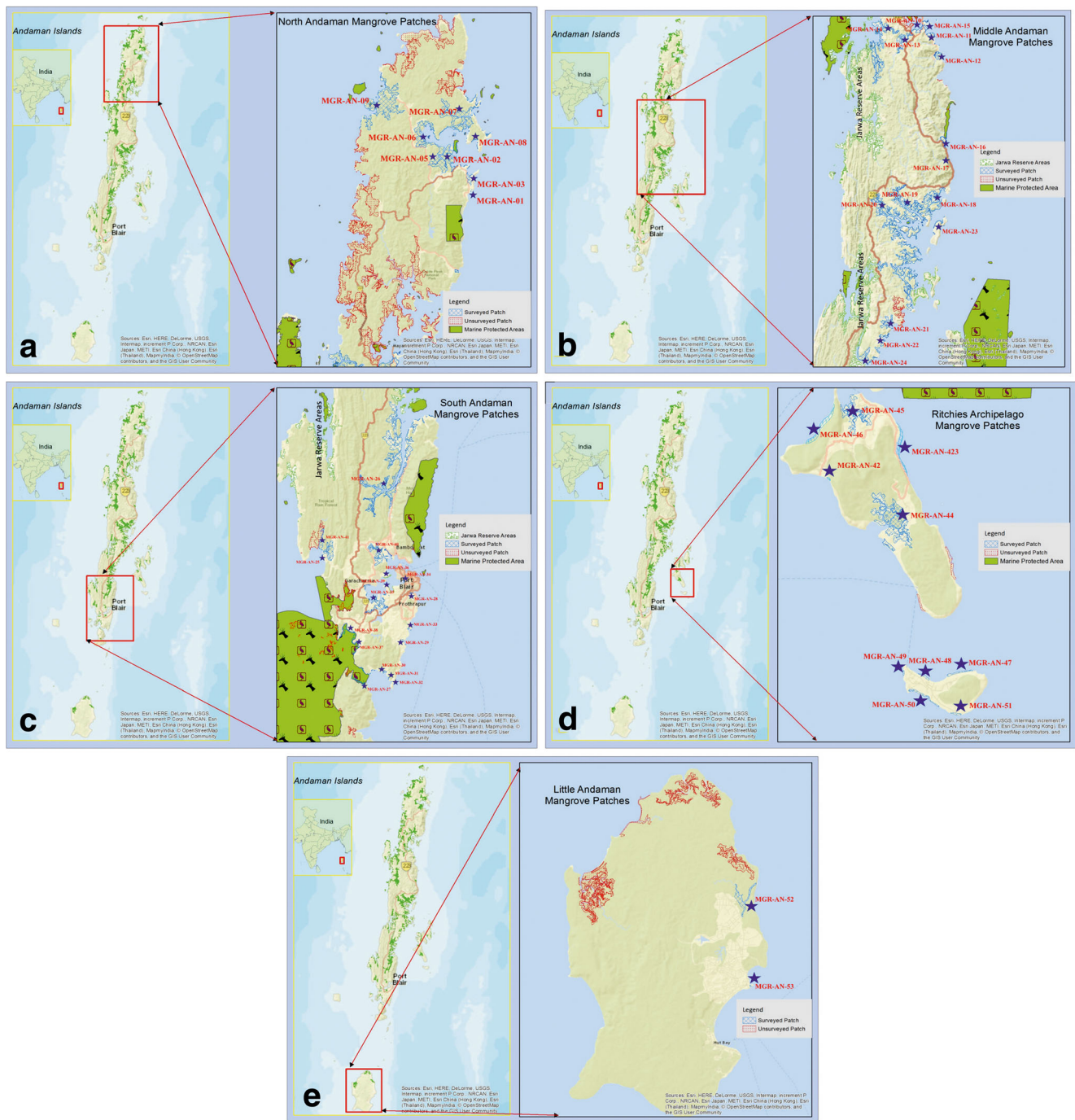| Regions	Number of patch delineated	Number patch surveyed	Number of patch unsurveyed
North Andaman	15	9	6
Middle Andaman	20	15	5
South Andaman	26	17	9
Ritchie's Archipelago	12	10	2
Little Andaman	6	2	4
Total	**79**	**53**	**26**

Fig. 1 Map showing the mangrove demarcation and survey sites of the Andaman Island

Data collection

Field surveys were conducted during June 2014 to March 2015. In each patch, multiple linear transects (100 m) were laid perpendicular to the water front, with a minimum of 50 m interval. Quantitative data on mangrove vegetative structures were collected by laying quadrats (10 × 10 m) along the line transects. In each line transect, three quadrats were laid at 0, 50 and 100 m.

Altogether, 178 quadrats were laid. Within each plot, all mangroves were identified to species level and counted according to three maturity categories as described by Menon (2006), *viz.*, trees (>4 m height), saplings (>1 m to ≤4 m height) and seedlings (plant ≤1 m height). The measurements *viz.*, tree height and girth at breast height (GBH) were noted for all trees and species-wise count data were collected for seedlings and saplings in each quadrat studied.

Table 2 Spatial extent of the mangroves of the Andaman Islands

Survey regions	Area (km^2)		No. of Units			Number of patches	
	Total area	Range of spatial extent	Small	Medium	Large	Isolated	Contiguous
North Andaman	233.76	0.000001 to 25.98	340	6	5	111	55
Middle Andaman	190.86	0.00025 to 16.84	239	4	5	45	39
South Andaman	201.57	0.000007 to 15.45	531	7	1	116	109
Ritchie's Archipelago	--	--	--	--	--	--	--
Little Andaman	21.26	0.002 to 4.17	4	--	--	--	4

Data analysis

The vegetation data were quantitatively analysed for abundance, density and frequency (Curtis and McIntosh 1950). The importance value index (IVI) for the tree species was determined as a sum of the relative frequency, relative density and relative dominance (Curtis 1959). In this study, the relative dominance was calculated based on the basal area of individual trees using GBH. Apart from this, various indices for assessing the health of the mangroves *viz.*, Shannon-Wiener diversity index (H') (Shannon and Weiner 1963), Margalef's species richness (d) (Margalef 1978), Pielou's evenness index (J') (Pielou 1966), Simpson's dominance index (D) (Simpson 1949), Complexity Index (I_c) (Holdridge 1967; Pool et al. 1977), Beta diversity (β-diversity) (Whittaker 1972) and Maturity Index Value (Nabi et al. 2012) were analyzed. Niche width was estimated to ascertain the adaptability of different mangrove species to tolerate conditions at the interface between different habitat types (Levins 1968). Similarity matrices between regions were constructed by using Bray-Curtis similarity index, based on the IVI of mangrove species. These matrices were used to display the similarity among the regions by means of hierarchical clustering (using group average method) and non-metric multidimensional scaling (nMDS). SIMPER analysis was performed to identify the mangrove species contributing for dissimilarity between regions. Cluster analysis, nMDS and SIMPER were performed using PRIMER v7 (Clarke and Gorley 2015). The floristic similarities between the different regions of Andaman Islands were examined based on the presence/absence of the species using the Sørensen (1948) Similarity Index, modified after Chao et al. (2006).

Results

Species composition

A total of 25 mangrove species belonging to 11 families and 14 genera were recorded in the Andaman Islands in the present study. Among the 11 families, number of species represented from the family Rhizophoraceae was the highest (8 species), followed by Lythraceae (4 species). Families of Avicennieaceae, Combretaceae, Euphorbiaceae and Meliaceae were represented by two species each, whereas Arecaceae, Leguminosae, Myrsinaceae, Rubiaceae and Sterculiaceae were represented by one species each. Number of mangrove species was found to be high in Middle Andaman (22 species), followed by South Andaman (15 species), Ritchie's Archipelago (14 species), North Andaman (12 species) and Little Andaman (8 species). Three mangrove species, which are categorized as threatened species according to IUCN red list, *viz., Phoenix paludosa* (Near Threatened), *Sonneratia ovata* (Near Threatened) and *Sonneratia griffithii* (Critically Endangered) were found in the Andaman Islands. Of these, *Phoenix paludosa* was distributed in North, Middle and South Andaman Islands, whereas *Sonneratia ovata* and *S. griffithii* were found in Ritchie's Archipelago and Middle Andaman, respectively (Table 3).

Structural features

The total tree density and stand basal area in Andaman Island were 1658/ha and 38.59 m^2/ha, respectively. Of the 25 species recorded, IVI for *Rhizophora apiculata* was the highest and three genera *viz., Rhizophora, Bruguiera* and *Ceriops* together constituted 67% of the IVI (Fig. 2). This shows the dominance of family Rhizophoraceae in the Andaman Islands. The overall IVI contribution of threatened species *viz., Sonneratia ovata* (0.27%), *Phoenix paludosa* (1.0%) and *Sonneratia griffithii* was very low (2.19%). Apart from these species, 16 species were having <5% of IVI, thus indicating their rarity in Andaman Islands. Among the recorded species, *Bruguiera gymnorhiza, Ceriops tagal, Heritiera littoralis, Rhizophora apiculata, R. mucronata* and *Xylocarpus granatum* were widely distributed in all the five regions surveyed.

Density and basal area of mangrove trees in the surveyed regions of Andaman Islands ranged from 1252 ha^{-1} to 2200 ha^{-1} and from 30.8 m^2/ha to 59.6 m^2/ha, respectively (Table 3). As tree density increased, basal area occupied by

Table 3 Distribution and structural pattern of mangroves of the Andaman Islands

Mangrove Species	IUCN status*	North Andaman			Middle Andaman			South Andaman			Ritchie's Archipelago			Little Andaman		
		Density	BA	IVI	Density	BA	IVI	Density	BA	IVI	Density	BA	IVI	Density	BA	IVI
Aegiceras corniculatum	LC	--	--	--	19.44	0.11	3.58	10.00	0.06	1.30	--	--	--	--	--	--
Avicennia marina	LC	14.81	0.61	7.66	62.50	2.06	14.25	256.00	2.95	34.93	12.50	0.08	2.93	--	--	--
Avicennia officinalis	LC	66.67	0.26	9.26	30.56	1.13	9.22	--	--	--	79.17	2.88	12.98	360.00	1.73	28.32
Bruguiera cylindrica	LC	22.22	0.37	7.64	16.67	0.19	4.03	14.00	0.02	3.33	12.50	0.41	3.68	--	--	--
Bruguiera gymnorhiza	LC	192.59	12.12	64.50	213.89	7.74	48.00	206.00	4.69	36.36	95.83	6.38	25.79	520.00	40.39	121.57
Bruguiera parviflora	LC	--	--	--	1.39	0.10	0.82	12.00	0.23	3.25	--	--	--	--	--	--
Ceriops tagal	LC	7.41	0.14	4.23	319.44	3.66	50.46	68.00	0.39	12.86	212.50	1.05	26.75	100.00	0.89	13.37
Cynometra iripa	LC	--	--	--	1.39	0.01	0.59	--	--	--	--	--	--	--	--	--
Excoecaria agallocha	LC	33.33	0.13	6.27	66.67	0.82	12.03	292.00	2.10	25.33	66.67	0.59	11.25	--	--	--
Excoecaria indica	DD	--	--	--	8.33	0.14	1.41	--	--	--	--	--	--	--	--	--
Heritiera littoralis	LC	25.93	0.10	5.60	23.61	1.16	6.43	22.00	0.07	4.48	70.83	4.72	18.64	40.00	0.21	9.11
Lumnitzera littorea	LC	--	--	--	44.44	0.39	6.52	110.00	1.49	12.45	--	--	--	--	--	--
Lumnitzera racemosa	LC	--	--	--	8.33	0.05	1.67	--	--	--	--	--	--	--	--	--
Pemphis acidula	LC	--	--	--	--	--	--	--	--	--	141.67	3.52	20.02	--	--	--
Phoenix paludosa	NT	22.22	0.04	3.51	19.44	0.03	3.39	32.00	0.08	3.67	--	--	--	--	--	--
Rhizophora apiculata	LC	403.70	9.25	83.83	322.22	7.42	61.70	818.00	13.34	106.01	320.83	4.08	41.73	120.00	3.16	24.90
Rhizophora mucronata	LC	444.44	10.87	89.61	162.50	6.79	38.19	260.00	3.56	34.49	537.50	12.58	83.24	300.00	12.08	55.90
Rhizophora sp.	--	--	--	--	11.11	0.64	2.83	--	--	--	66.67	4.67	18.28	460.00	0.99	38.96
Rhizophora stylosa	LC	--	--	--	13.89	0.67	4.05	--	--	--	--	--	--	--	--	--
Scyphiphora hydrophyllacea	LC	--	--	--	--	--	--	18.00	0.03	2.87	--	--	--	--	--	--
Sonneratia alba	LC	3.70	0.19	2.43	12.50	0.99	4.73	60.00	1.60	13.17	104.17	2.95	24.77	--	--	--
Sonneratia griffithii	CE	--	--	--	8.33	5.09	15.33	--	--	--	--	--	--	--	--	--
Sonneratia ovata	NT	--	--	--	--	--	--	--	--	--	16.67	0.70	4.55	--	--	--
Xylocarpus granatum	LC	14.81	4.92	15.44	19.44	1.96	9.96	22.00	0.18	5.51	8.33	0.38	5.40	20.00	0.10	7.88
Xylocarpus moluccensis	LC	--	--	--	1.39	0.09	0.80	--	--	--	--	--	--	--	--	--
Total		1251.9	39.0	300.0	1387.5	41.2	300.0	2200.0	30.8	300.0	1745.8	45.0	300.0	1920.0	59.6	300.0

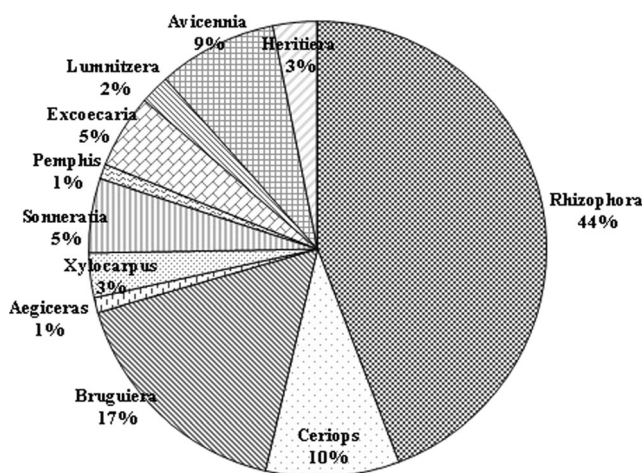* LC- least Concern, NT – Near Threatened, CE – Critically Endangered, DD – Data Deficient

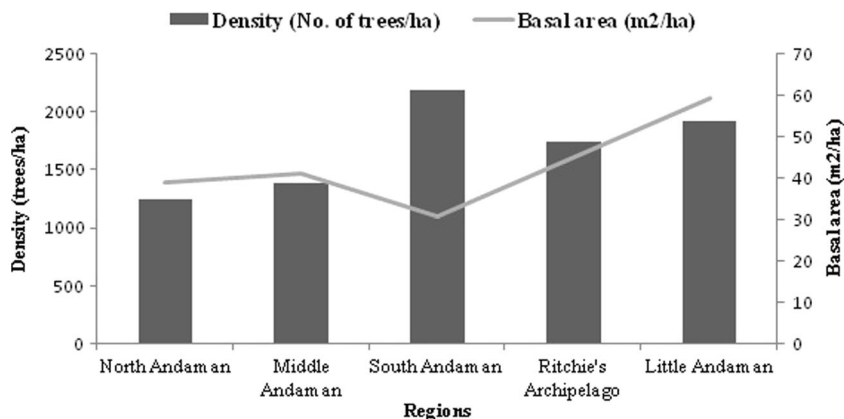Fig. 2 Species composition in Andaman Island based on IVI percentage

Table 4 Dominant and co-dominant mangrove species in the Andaman Islands on the basis of Important Value Index (IVI)

Island group	Representing Community	
	Dominant Species	Co-dominant Species
North Andaman	*Rhizophora mucronata*	*Rhizophora apiculata*
Middle Andaman	*Rhizophora apiculata*	*Ceriops tagal*
South Andaman	*Rhizophora apiculata*	*Bruguiera gymnorhiza*
Ritchie's Archipelago	*Rhizophora mucronata*	*Rhizophora apiculata*
Little Andaman	*Bruguiera gymnorhiza*	*Rhizophora mucronata*
Andaman (all regions)	*Rhizophora apiculata*	*Rhizophora mucronata*

trees also increased in the studied regions except for South Andaman, which showed an inverse relationship between them (Fig. 3). Dominance of individuals with low DBH size class (<40 cm) could be attributed to the low basal area and high density in South Andaman Island. Interestingly, in all the regions, the maximum tree density was contributed by mangrove species belonging to the family Rhizophoraceae *viz., Rhizophora mucronata* in North Andaman (444.4 ha^{-1}) and Ritchie's archipelago (537.5 ha^{-1}); *R. apiculata* in Middle Andaman (322.2 ha^{-1}) and South Andaman (818 ha^{-1}); and *Bruguiera gymnorhiza* in Little Andaman (520.0 ha^{-1}). Similarly, species of Rhizophoraceae family were observed to have attained the maximum basal areas in all regions as follows: *Bruguiera gymnorhiza* in North Andaman (12.12 m^2/ha); Middle Andaman (7.74 m^2/ha) and Little Andaman (40.39 m^2/ha); *R. apiculata* in South Andaman (13.34 m^2/ha); and *R. mucronata* in Ritchie's Archipelago (12.58 m^2/ha) (Table 3). Accordingly, IVI of these species were also the highest in their respective regions, which indicated their significant contribution to the overall community structure. On the basis of IVI, it was found that North Andaman and Ritchie's archipelago were represented by *Rhizophora* community; Middle Andaman by *Rhizophora-*

Ceriops community, South Andaman by *Rhizophora-Bruguiera* community and Little Andaman by *Bruguiera-Rhizophora* community (Table 4). The study revealed that the mangrove forests of the Island were characterized by a mixed species composition, all belonging to the family Rhizophoraceae. Shallower slopes in dominance-diversity curve (log normal) (Fig. 4) indicated higher evenness among the assemblages of mangrove species in all regions. Frequency of mangrove trees belonging to 20–40 cm GBH was the highest in all the regions except for Little Andaman, where the trees with <20 cm GBH had greater frequency (Fig.5). It is also evident that beyond 20–40 cm GBH class, the number of tree stands gradually decreased with the increase in GBH of trees. However, this pattern was not consistent for the mangroves in Little Andaman.

Niche width measures the degree of specialization of a species and its ability to exploit an environmental range in space and also to maintain its population in different environments (Kalakoti et al. 1987). The species with wider niches are considered to be more generalized (Smith 1980). Across all regions, the highest niche width was exhibited by the species *Rhizophora apiculata* (23.7) followed by *R. mucronata* (16.07) and *Bruguiera gymnorhiza* (13.93) suggesting their better adaptation to environmental conditions in all these regions (Table 5). Niche width of mangrove species in Little Andaman was found to be uniformly low. However,

Fig. 3 Tree density and basal area relationship in different regions of the Andaman Islands

Fig. 4 Dominance-diversity curves for mangrove stands in different regions of the Andaman Islands
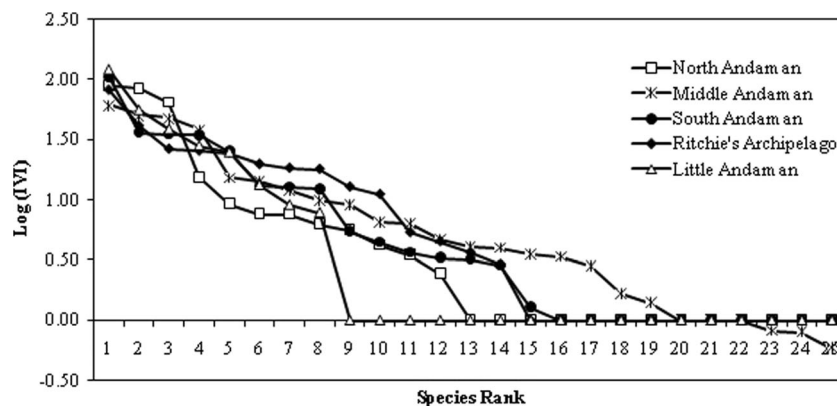
mangroves of Little Andaman had high complexity index (I_c = 507.48), which could be attributed to the presence of taller trees (11.1–15.3 m) and high stand basal areas (59.6 m^2 ha^{-1}). Structural complexities of mangroves increased gradually from North Andaman to Little Andaman, which was reflected in their I_c values (Table 6). Maturity index value (MIV) also showed that mangrove stands in Little Andaman had comparatively higher maturity (MIV = 37.5) than the stands in other regions (Table 6). However, MIV values for all regions were far less than the maximum value of 100, indicating their low degree of maturity (MIV for Andaman Island = 11.0).

Variability among the patches

Among 53 patches studied, number of species recorded was maximum in Betapur (14 species) followed by Rangat Bay, Yerrata, Namunagar and Manjery (Table 7). Diversity index also was the highest for Betapur (H' = 2.3). Total tree density was the highest in Aerial Bay whereas stand basal area was the highest in Long Island. The patch -specific information is summarized below.

North Andaman

Among the 9 patches surveyed in North Andaman, maximum number of species was recorded from Aerial Bay and Ramnagar (7 species each). Total tree density was high in

Aerial Bay (1.03/m^2), whereas stand basal area was high in Milangram (95.44 m^2/ha) (Table 7). Tree density was the lowest in Shyam Nagar, followed by Milangram, Swarajgram, and Laximupur. However, the estimated stand basal areas of all the patches, except Shyam Nagar, in the North Andaman Islands, were greater than 25m^2/ha, indicating the pristine nature of mangrove forests. Low stand basal area in Shyam Nagar (<10 m^2/ha) suggested the disturbed nature of mangrove forests. Shyam Nagar is the only mangrove patch located in west coast of North Andaman Island, whereas all the other surveyed patches were located on the eastern coast. Thus, the study showed that the impact of the land upheaval in North Andaman following the 2004 catastrophic earth quake was more on the west coast than the east coast of Andaman.

Middle Andaman

Out of the 15 patches surveyed in Middle Andaman, mangrove species diversity was the maximum in Betapur (14 species), followed by Rangat Bay and Yerrata (Table 7). Tree density was the highest at Rangat Bay (0.75/m^2) and the lowest at Wrafter's Creek (0.14/m^2). Except for three patches (Katan, Yerrata, and Rangat Bay), all the other patches showed stand basal area greater than 25m^2/ha, which indicated the pristine nature of mangroves of Middle Andaman Island (Komiyama et al. 2008). Stand basal area was the highest at Long island (137.36m^2/ha), followed by Panchawati (124.32 m^2/ha) and Tugapur (119.62 m^2/ha.

Fig. 5 Girth at breast height (cm) distribution of mangrove trees in different regions of the Andaman Islands
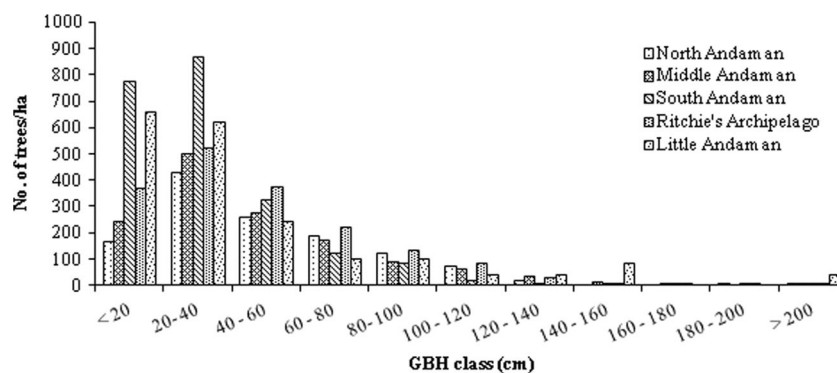
Table 5 Niche widths of mangrove species in different regions of the Andaman Islands

Species	North Andaman	Middle Andaman	South Andaman	Ritchie's Archipelago	Little Andaman
Aegiceras corniculatum	--	1.6	1.0	--	--
Avicennia marina	2.9	2.9	4.7	1.0	--
Avicennia officinalis	1.0	2.7	--	1.0	1.0
Bruguiera cylindrica	1.6	3.2	1.7	1.0	--
Bruguiera gymnorhiza	3.5	5.1	4.1	1.0	1.1
Bruguiera parviflora	--	1.0	2.0	--	--
Ceriops tagal	1.9	8.8	6.1	1.1	1.0
Cynometra iripa	--	1.0	--	--	--
Excoecaria agallocha	1.4	3.9	2.5	1.0	--
Excoecaria indica	--	1.0	--	--	--
Heritiera littoralis	1.8	2.1	1.7	1.0	1.0
Lumnitzera littorea	--	2.8	1.3	--	--
Lumnitzera racemosa	--	1.2	--	--	--
Pemphis acidula	--	--	--	1.8	--
Phoenix paludosa	1.0	2.9	1.3	--	--
Rhizophora apiculata	4.3	9.4	10.6	3.3	1.0
Rhizophora mucronata	5.1	2.9	5.8	4.1	1.0
Rhizophora sp.	--	1.0	--	1.1	1.0
Rhizophora stylosa	--	1.0	--	--	--
Scyphiphora hydrophyllacea	--	--	1.8	--	--
Sonneratia alba	1.0	1.9	3.1	2.0	--
Sonneratia griffithii	--	2.2	--	--	--
Sonneratia ovata	--	--	--	1.0	--
Xylocarpus granatum	1.0	3.2	4.2	2.0	1.0
Xylocarpus moluccensis	--	1.0	--	--	--

Though mangrove patch of Panchawati had the second highest stand basal area, tree density was comparatively lower. This indicates the occurrence of trees with higher GBH size classes (>40 cm). For instance, *S. griffithii*, one of the critically endangered species, constitute 76.5% of the stand basal area in Panchwati, whereas it contributes only 6.67% to the total tree density of the islands and the mean GBH was 236 cm. Low stand basal area and higher tree density of mangrove patches of Yerrata, Rangat and Katan showed the dominance of adult individual trees with smaller GBH classes (<40 cm). High density and low basal area are quite common in the developing forest (Twilley 1995).

South Andaman

In South Andaman, a total of 17 patches were surveyed and the maximum number of species was recorded from Manjery and Naminagar (10 species each). Total tree density was high at Chidiyatapu I (1.03/m^2) and stand basal area was high at

Rutland (124.2 m^2/ha) (Table 7). Most of the mangrove patches in South Andaman Islands had high tree density and low stand basal areas, which indicated the maturing potential and high abundance of adult individual trees with low GBH size class (20-40 cm). However, mangrove patches of Kodiyaghat and Collinpur were observed to have the lowest densities and high basal area suggesting that the mangrove forests in these places were mature and comprised of individuals of high GBH size class (>40 cm).

Ritchie's Archipelago

In Ritchie's Archipelago, out of the 12 patches delineated, ten patches were surveyed. The maximum number of species was recorded from Radhanagar (9 species), where the tree density was also the highest (0.33/m^2). Stand basal area was the highest in Havelock beach (92.87 m^2/ha) (Table 7). Tree density and basal area (<25m^2/ha) were lower in Bharatpur, Sitapur and Laxmanpur, indicating low structural

Table 6 Complexity, maturity, diversity and evenness patterns of mangrove stands in the Andaman Islands

Parameters	Regions					Andaman (All regions)
	North Andaman	Middle Andaman	South Andaman	Ritchie's Archipelago	Little Andaman	
Tree height (m)	6.2–15.8	7.7–15.7	8.9–16.3	6.8–16.1	11.1–15.3	6.2–16.3
Complexity index (Ic)	196.84	240.57	265.82	286.38	507.48	254.72
Maturity Index Value	18.8	13.3	20.4	14.6	37.5	11.0
Species richness (S)	12	22	15	14	8	25
Mean species richness	3.78	6.47	5.00	3.40	4.50	4.89
β-diversity	2.2	2.4	2.0	3.1	0.8	4.1
Margalef's richness Index (d)	1.89	3.04	2.00	2.15	1.53	3.00
Shannon & Weiner Index (H)	1.65	2.24	1.99	2.12	1.76	2.28
Simpson index (1-D)	0.74	0.85	0.80	0.84	0.80	0.85
Pielou's eveness Index (J')	0.66	0.72	0.74	0.80	0.84	0.71

development of mangrove forest. In Neil Kendra, tree density was the lowest and basal area was comparatively higher, which indicated the dominance of mature trees. Comparatively, mangrove patches of Ritchie's Archipelago were found to have low structural development.

Little Andaman

In Little Andaman, out of the six patches mapped, two patches were surveyed and the maximum number of species was recorded from V.K. Pur (6 species), where the tree density ($0.24/m^2$) and stand basal area (73.04 m^2/ha) were also high (Table 7). *Bruguiera gymnorrhiza* was the dominant species in V. K. Pur, whereas *Rhizophora apiculata* was the predominant mangrove species in Kalapathar.

Diversity pattern

The Shannon diversity index and Simpson index (1-D) for the whole ANI were estimated as 2.28 and 0.85, respectively. Values of β-diversity ranged from 0.8 to 3.1 in the studied regions of Andaman Islands (Table 6). Shannon-Wiener indices ranged from 1.65 to 2.24, indicating a high level of mangrove diversity in all regions of Andaman. Further, higher values of Simpson index (1-D = 0.74 to 0.85) and Pielou's evenness index ('J' = 0.66 to 0.84) indicated the presence of high mangrove diversity and their even distribution in all regions. Among the regions, richness (d = 3.04) and diversity (H = 2.24; 1-D = 0.85) of mangrove species were the highest in Middle Andaman, which were similar to the overall richness and diversity observed for the Andaman Islands (d = 3.00; H = 2.28; 1-D = 0.85) (Table 6). Sørensen similarity indices between the survey regions were high (> 0.6; Table 9), indicating the close floristic affinities between the surveyed regions.

Based on the IVI of mangrove species, cluster analysis (CA) as well as nMDS ordination grouped the five regions of the Andaman Islands into three main groups: Cluster 1 composed of North Andaman, Middle Andaman and South Andaman; Cluster 2 and Cluster 3 having Ritchie's Archipelago and Little Andaman respectively (Fig. 6). SIMPER analysis revealed a high level of dissimilarity of mangrove community structure between South Andaman and Little Andaman (60.44%), and the lowest level of dissimilarity between Middle Andaman and South Andaman (32.73%, Table 8). Dissimilarities of mangrove community structure among the studied regions were mainly contributed by *Rhizophora apiculata* (19.2 to 23.1%), *R. mucronata* (18.6 to 25.9%) and *Bruguiera gymnorhiza* (23.5 to 35.7%), all belonging to the family Rhizophoraceae.

Discussion

Species composition

The earliest reference on mangrove floristics of the ANI listed 27 species (Parkinson 1923). Subsequently, no significant change in mangrove floristics of ANI was reported till 1986. Singh et al. (1987) reported five new records viz., *Bruguiera sexangula*, *Bruguiera cylindrica*, *Rhizophora stylosa*, *R. × lamarckii* and *Acrostichum speciosum* from ANI. In recent times six new records viz., *Sonneratia ovate*, *Sonneratia lanceolata*, *S. × urama*, *S. × gulngai*, *Rhizophora × annamalayana* and *Excoecaria indica* and three new entities, viz., *Rhizophora mucronata* var. *alokii*, *Acrostichum* hybrid and *Rhizophora × mohanii* have also been reported from the ANI (Goutham-Bharathi et al. 2012; Ragavan et al. 2015a,b). Mangroves of the ANI, represented by 38 true mangrove

Table 7 Patch-wise structural parameters in the Andaman Islands

Site name	Code	No of species	Tree density (/m^2)	Basal area (m^2/ha)	Diversity (H')	Richness (d)	Evenness (J')
North Andaman							
Kalipur	MGR-AN-01	3	1.03	28.27	0.38	0.37	0.34
Aerial Bay	MGR-AN-02	7	1.95	26.56	0.52	0.9	0.26
Durgapur	MGR-AN-03	5	0.47	33.93	0.91	0.8	0.56
Ramnagar	MGR-AN-04	7	0.66	69.59	1.32	1.13	0.67
Laxmipur	MGR-AN-05	3	0.21	38.31	0.75	0.48	0.68
Swarajgram	MGR-AN-06	3	0.21	37.31	0.71	0.46	0.68
Milangram	MGR-AN-07	6	0.22	95.44	1.44	1.32	0.8
Mangrove Point	MGR-AN-08	8	0.40	61.31	1.64	1.31	0.78
Shyam Nagar	MGR-AN-09	5	0.21	8.75	1.29	0.86	0.8
Middle Andaman							
Danapur	MGR-AN-10	4	0.50	41.17	1.01	0.65	0.72
Rampur	MGR-AN-11	4	0.22	47.92	1.01	0.71	0.72
Karmatang	MGR-AN-12	4	0.57	86.69	1.13	0.63	0.81
Tugapur	MGR-AN-13	4	0.49	119.32	1.33	0.6	0.95
Austin creek	MGR-AN-14	8	0.40	60.87	1.2	1.09	0.57
Pokkadera	MGR-AN-15	4	0.35	90.53	1.45	1.01	0.80
Betapur	MGR-AN-16	14	0.27	64.3	2.3	2.54	0.9
Panchawati	MGR-AN-17	4	0.20	124.32	0.7	0.72	0.5
Rangat Bay	MGR-AN-18	12	0.75	19.69	1.8	1.79	0.72
Yerrata	MGR-AN-19	12	0.56	13.75	1.87	1.89	0.72
Shyamkund	MGR-AN-20	6	0.42	44.82	1.16	0.9	0.64
Sundergarh	MGR-AN-21	5	0.67	48.03	1.25	0.66	0.77
Katan	MGR-AN-22	9	0.43	7.65	1.61	1.44	0.73
Long Island	MGR-AN-23	6	0.23	137.36	1.18	1.18	0.65
Wrafters creek	MGR-AN-24	4	0.15	27.48	0.87	0.66	0.62
South Andaman							
Collinpur	MGR-AN-25	4	0.15	80.31	1.21	0.88	0.87
Shoal Bay	MGR-AN-26	8	0.75	37.52	1.73	1.23	0.83
Rutland	MGR-AN-27	5	0.32	124.2	1.25	0.76	0.77
Carbyn cove	MGR-AN-28	4	0.27	33.99	1.3	0.68	0.93
Burmanallah	MGR-AN-29	5	0.60	92.62	1.22	0.84	0.76
Kodiyaghat	MGR-AN-30	5	0.08	41.75	1.37	1.44	0.85
Chidiyatapu 1	MGR-AN-31	4	1.03	27.31	1.06	0.65	0.76
Chidiyatapu 2	MGR-AN-32	3	0.42	9.19	0.89	0.45	0.8
Bedanabad	MGR-AN-33	8	0.37	42.85	1.58	1.40	0.75
Junglighat	MGR-AN-34	3	0.18	19.24	1.07	0.69	0.97
Ograbraj	MGR-AN-35	5	0.19	16.21	1.29	1.1	0.8
NamuNagar	MGR-AN-36	10	0.77	12.98	1.59	1.57	0.69
Manjery	MGR-AN-37	10	0.55	26.22	1.63	1.55	0.7
Guptapara	MGR-AN-38	3	0.57	26.78	0.72	0.42	0.66
Dollugunj	MGR-AN-39	9	0.88	7.51	1.5	1.36	0.68
Bambooflat	MGR-AN-40	9	0.77	24.86	1.3	1.4	0.59
Trirur	MGR-AN-41	2	0.36	24.72	0.68	0.2	0.98
Ritchies Archipelago							
Radha Nagar	MGR-AN-41	9	0.33	59.67	1,40	1.74	0.63
Govind Nagar	MGR-AN-42	2	0.28	32.78	0.67	0.24	0.96
Kalapathar	MGR-AN-43	4	0.17	48.29	1.11	0.85	0.8
Havelock Beach	MGR-AN-44	3	0.15	92.87	0.99	0.59	0.9

Table 7 (continued)

Site name	Code	No of species	Tree density (/m²)	Basal area (m²/ha)	Diversity (H')	Richness (d)	Evenness (J')
Near elephant Beach	MGR-AN-45	5	0.16	62.64	1	1.03	0.62
Neil Kendra	MGR-AN-46	2	0.04	43.01	0.54	0.38	0.77
Laxmanpur	MGR-AN-47	1	0.10	20.23	0	0	0
Ramnagr	MGR-AN-48	4	0.23	46.59	0.93	0.78	0.67
Sitapur	MGR-AN-49	5	0.11	21.59	1.14	1.13	0.7
Bharatpur	MGR-AN-50	3	0.06	24.95	0.933	0.62	0.84
Little Andaman							
V.K.pur creek	MGR-AN-52	6	0.25	73.04	1.47	1.08	0.82
Kalapthar	MGR-AN-53	4	0.14	7.76	0.65	0.9	0.46

species, account for approximately 50% of all mangrove species in the world (Ragavan et al. 2016a,b).

The reduction in the number of species reported in this study - could be attributed essentially to the differences in sampling locations (Whitmore 1990). The Andaman Islands are uniform in climatic and physiographic conditions and contribute to medium level of tree species diversity (Padalia et al. 2004). Among the five regions surveyed, except Ritchie's Archipelago, all the other regions had estuarine type of mangroves, fringing the creeks to varying widths, whereas in Ritchie's Archipelago mangroves were of coastal/fringe type. Generally, riverine mangroves develop the most structural complexity than fringe and basin forests and exhibit much higher value of complexity index than other habitats (Cintron et al. 1980). Coastal type mangroves are reported to have less diversity and zonation pattern (Utawale et al. 1973). Thus, mangroves in Ritchie's Archipelago had shown low structural development, despite high species diversity than those of North Andaman and Little Andaman. The tree density in North Andaman was the lowest in the Andaman Islands. The low density and diversity in the North Andaman can be attributed to the land upheaval and easterly tilt of land caused by 2004 massive earthquake (Malik and Murty 2005; Ray and Acharyya 2007, 2011). Particularly, the uplift was more on the western side than on the eastern side of the Island - The uplift of land caused the significant reduction in mangrove area of North Andaman; however, its effects on individual species could not be assessed due to lack of patch-specific information. A change in the composition of mangrove stands of ANI following the land subsidence/ upheaval was reported by Roy and Krishnan (2005). Coastal areas of South Andaman Islands were affected by subsidence. However, high tree density reported in this study supports the colonisation ability of mangroves in the submerged areas, which were inferred in earlier studies (Das et al. 2014).

Structural features

In total, 3073 mangrove plants were enumerated in 178 quadrats laid in the Andaman Islands in the present study, of which
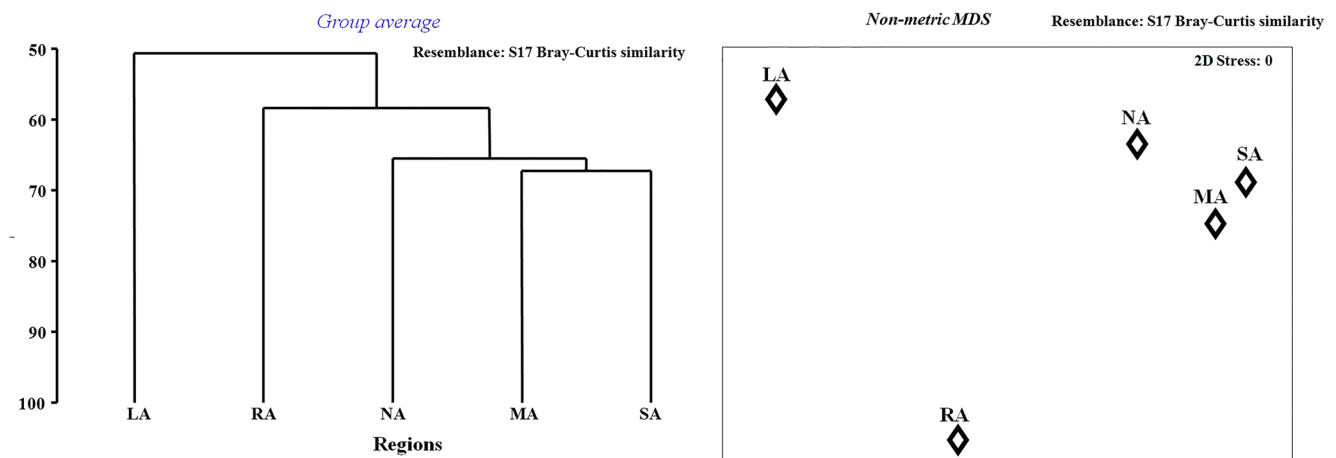

Fig. 6 Hierarchical clustering and nMDS scaling of mangrove patches in the Andaman Islands based on Importance Value Index of mangrove species (NA – North Andaman, MA – Middle Andaman, SA – South Andaman, RA – Ritchie's Archipelago, LA – Little Andaman)

Table 8 SIMPER dissimilarity analysis of mangrove species between pairs of regions in the Andaman Islands

Species	Average abundance	Average abundance	Average dissimilarity	Contribution %
Regions: NA and MA (Average dissimilarity: 33.09)				
	NA	MA		
Rhizopora mucronata	89.60	38.20	8.57	25.89
Ceriops tagal	4.20	50.50	7.72	23.32
Rhizophora apiculata	83.80	61.70	3.68	11.13
Bruguiera gymnorhiza	64.50	48.00	2.75	8.31
Regions: NA and SA (Average dissimilarity: 35.96)				
	NA	SA		
Rhizophora mucronata	89.60	34.50	9.18	25.54
Bruguiera gymnorhiza	64.50	36.40	4.68	13.03
Avicennia marina	7.70	34.90	4.53	12.61
Rhizophora apiculata	83.80	106.00	3.70	10.29
Regions: NA and RA (Average dissimilarity: 36.48)				
	NA	RA		
Rhizophora apiculata	83.80	41.70	7.02	19.24
Bruguiera gymnorhiza	64.50	25.80	6.45	17.69
Ceriops tagal	4.20	26.70	3.75	10.28
Sonneratia alba	2.40	24.80	3.73	10.24
Regions: NA and LA (Average dissimilarity: 42.57)				
	NA	LA		
Rhizophora apiculata	83.80	24.90	9.82	23.06
Bruguiera gymnorhiza	64.50	121.60	9.52	22.36
Rhizophora sp.	0.0	39.00	6.50	15.27
Rhizophora mucronata	89.60	55.90	5.62	13.19
Regions: MA and SA (Average dissimilarity: 32.73)				
	MA	SA		
Rhizophora apiculata	61.70	106.00	7.38	22.56
Ceriops tagal	50.50	12.90	6.27	19.14
Avicennia marina	14.30	34.90	3.43	10.49
Sonneratia griffithii	15.30	0.00	2.55	7.79
Regions: MA and RA (Average dissimilarity: 40.39)				
	MA	RA		
Rhizophora mucronata	38.20	83.20	7.50	18.57
Ceriops tagal	50.50	26.70	3.97	9.82
Bruguiera gymnorhiza	48.00	25.80	3.70	9.16
Sonneratia alba	4.70	24.80	3.35	8.30
Regions: MA and LA (Average dissimilarity: 49.74)				
	MA	LA		
Bruguiera gymnorhiza	48.00	121.60	12.26	24.66
Ceriops tagal	50.50	13.40	6.18	12.43
Rhizophora apiculata	61.70	24.90	6.13	12.33
Rhizophora sp.	2.80	39.00	6.03	12.13
Regions: SA and RA (Average dissimilarity: 48.16)				
	SA	RA		
Rhizophora apiculata	106.00	41.70	10.72	22.26
Rhizophora mucronata	34.50	83.20	8.12	16.86
Avicennia marina	34.90	2.90	5.33	11.08
Pemphis acidula	0.00	20.00	3.33	6.92
Regions: SA and LA (Average dissimilarity: 60.44)				
	SA	LA		
Bruguiera gymnorhiza	36.40	121.60	14.20	23.49
Rhizophora apiculata	106.00	24.90	13.51	22.36
Rhizophora sp.	0.0	39.00	6.50	10.75
Avicennia marina	34.90	0.0	5.82	9.62
Regions: RA and LA (Average dissimilarity: 44.73)				
	RA	LA		
Bruguiera gymnorhiza	25.80	121.60	15.97	35.69
Rhizophora mucronata	83.20	55.90	4.55	10.17
Sonneratia alba	24.80	0.0	4.13	9.24
Rhizophora sp.	18.30	39.00	3.45	7.71

NA – North Andaman, MA – Middle Andaman, SA – South Andaman, RA – Ritchie's Archipelago, LA – Little Andaman

Table 9 Sørensen Similarity index of mangroves in different regions of Andaman

Survey regions	Sorenson Similarity index				
	North Andaman	Middle Andaman	South Andaman	Ritchie's Archipelago	Little Andaman
North Andaman	0.70	0.81	0.84	0.70	
Middle Andaman		0.76	0.66	0.53	
South Andaman			0.69	0.52	
Ritchie's Archipelago				0.72	
Little Andaman					

trees, saplings and seedlings accounted for 96.06%, 1.99% and 1.95% respectively. The low contribution of seedlings and saplings in the Andaman Islands could be attributed to the dense canopy and lack of canopy gap in surveyed sites. Very dense mangrove comprised 65% of the mangrove cover in the ANI (FSI 2015). Creation of canopy gap could be a key driver in the natural regeneration of the tropical mangrove, and in particular *Rhizophora* dominated mangroves (Kathiresan and Bingam 2001). The presence of dense canopy does not allow full penetration of solar radiation, which is a necessary factor for the growth of plants. Thus, the mangrove community in the Andaman Islands was found to be dominated by tree stands. Tree density in the Andaman Islands ranged from 0.05 to 0.5 individual/m^2 and the tree density was 0.16 individual/m^2, which was almost similar to the values reported for the mangrove forests in Thailand (Chasang 1984 and Macintosh et al. 2002) and Indonesia (Hinrichs et al. 2009) suggesting close floristic affinities of the Islands towards the Southeast Asian countries.

Most studies on the vegetative structure of the mangrove forests of the Andaman Islands (Mall et al. 1982, Dagar et al. 1991, Singh and Garge 1993) were from South Andaman, which is the most intensively studied region in Andaman (Goutham-Bharathi et al. 2014). According to Mall et al. (1982), the mangrove forests of South Andaman had a density of 0.11 individual/m^2. Twenty-two years later, Padalia et al. (2004) reported a density of 0.067 individual/m^2. According to the findings of Das et al. (2014), mangrove density in the Andaman Islands ranged from 3.07 to 5.69 individuals/m^2. In the present study, the stand basal area in Andaman Islands ranged between 12.34 m^2/ha and 295.5 m^2/ha, which is higher than that reported from Malaysia (1.5 to 49 m^2/ha; Satyanarayana et al. 2010;) and Srilanka (48.25 to 27.1 m^2/ha; Perara et al. 2013). Padalia et al. (2004) reported a stand basal area of 7.92 m^2/ha from the Andaman Islands; this low basal area could be attributed to less sampling efforts. Pristine mangrove forests with minimal impacts have been shown to have a basal area of >25 m^2 ha^{-1} (Komiyama et al. 2008; Kauffman et al. 2011); secondary forest has been found to have basal areas of around 15 m^2 ha^{-1} (Komiyama et al.

2008; Cavalcanti et al. 2009), and disturbed forests show basal areas of <10 m^2 ha^{-1} (Komiyama et al. 2008). In the present study, the observed stand basal areas of all the five surveyed regions were greater than 25 m^2/ha, indicating that the mangroves in Andaman Islands are intact and pristine. High basal area can also be attributed to the low population density of species (Padalia et al. 2004). It was evident from this study that certain species with higher basal areas were reported with lower density of adult trees. This low tree density and high basal area are indicative of mature forests, with a good structural development (Cintron and Schaefer-Novelli 1983; Jimenez Lugo and Cintron 1985; Fromard et al. 1998).

Rarity in natural systems is common and is most often defined by two attributes: the species distribution and its abundance (Flather and Sieg 2007). Except for the colonizing/pioneering species of the family Rhizophoraceae, like *Rhizophora apiculata*, *R. mucronata*, *Bruguiera gumnorhiza* and *Ceriops tagal,* all the other true mangrove species encountered in the present study strongly exhibited a negative correlation between relative frequency and relative abundance. Therefore, species with restricted distribution should be studied extensively and species-specific conservation should be taken.

Higher population of *Rhizophora apiculata*, *R. mucronata* and *Bruguiera gymnorhiza* indicated their wide distribution/dominance in Andaman Islands, compared to another mangrove species. Population status of threatened species (*Phoenix paludosa, Sonneratia griffithii* and *S. ovata*) was <25 individuals/ha in the Andaman Islands, which emphasized the need of their conservation. Based on the overall stand basal area, it was evident that the mangrove stands in Andaman Islands were composed of uneven, aged, mixed mangrove forest with good structural development. Further, the frequency of occurrence was the highest for the 20–40 cm girth class, indicating that the mangrove community was still in growing phase, as also reported by earlier researchers (Balachandra 1988, Padalia et al. 2004). The low maturity index value (less than 100) also indicated the developing phase of Andaman mangroves. Complexity Index (Ic) is often used for quantitative description of the structural complexity of the tropical vegetation (Pool et al. 1977). These values for

Andaman mangroves were far greater than reported in the earlier studies (Pool et al. 1977; Fromard et al. 1998; Amarasinghe and Balasubramaniam 1992), but were similar to the mangroves of Odisha (Upadhyay and Mishra 2014). The high complexity index values recorded in the present study could be attributed to dominance by riverine type of mangroves in Andaman Islands. In general, low β-diversity (<1) indicated low heterogeneity and values >5 shows high heterogeneity in forest structure (McCune and Grace 2002). The lowest β-diversity (<1.0) recorded in Ritchie's Archipelago indicated the homogenous nature of mangroves. Other regions had relatively high β-diversity (≥2) indicating the extent of change in mangrove community composition in those regions. Overall β-diversity in Andaman Island (β_w = 4.1) suggested a high level of heterogeneity between the regions in terms of mangrove communities.

Diversity pattern

Diversity pattern of mangrove species in the present study was found to be in agreement with the pattern described by Ragavan et al. (2015a,b). Cluster analysis and nMDS ordination clearly distinguished Little Andaman from the other studied regions in Andaman Islands. Though the clustering was explained by importance values of mangrove species, Little Andaman was found to have the lowest species richness (8 species), highest basal area (59.6 m²/ha), highest complexity index (507.4), highest maturity (37.5), lowest β-diversity (0.8) and low niche width of mangrove species (≤1.1).

Role of mangroves in coastal protection

Biological structures such as mangrove forests, salt marshes, seagrass beds and coral reefs attenuate waves and as a result provide coastal protection (Koch et al. 2009). Recently Yulianda et al. (2014) studied the influences of mangroves on the coastal conservation and found that density and thickness of mangroves growing on the seashore significantly contribute to maintaining the stability of the coast. It has also been known that coastlines with and without mangroves respond differently and mangrove-dominated coastal segments exhibit less erosion while non-vegetated segments or former mangrove areas incur substantial erosion (Thampanya et al. 2006). The protective role of mangrove forest against catastrophic events like cyclones, storms, tsunami etc., have been widely reported (Badola and Hussain 2005; Danielson et al. 2005; Kathiresan and Rajendran 2005; Iverson and Prasad 2007; Malik et al. 2015). However, few studies have reported the inefficiency of mangroves against long waves, including storm surges and tsunami (Kerr et al. 2006; Dahdough-Guebas, 2006; Yanagisawa et al. 2009). Recent research regarding the extent of coastal protection provided by mangroves includes observational studies, numerical modeling, and laboratory experiments (Marois and Mitsch

2015). Of these, observational studies have not provided conclusive results, whereas, numerical and physical models support the mitigating capabilities of mangroves for cyclone storm surges and small tsunamis (Hiraishi and Harada 2003; Yanagisawa et al. 2010; Zhang et al. 2012). The density and width of mangrove vegetation is expected to affect the ability of mangroves to reduce effects storm surge and tsunamis (Krauss et al. 2009; Zhang et al. 2012). Increased mangrove densities decreased the maximum water level, run-up height, and maximum flow speed (Gelfenbaum et al. 2007) and mangrove belts of several hundred meters wide are expected to reduce flood depth by 5 to 30%. Furthermore, the capacity of mangroves to reduce hazards may be limited by characteristics of the hazard, such as tsunami height or wind speeds during cyclones, which can also destroy mangroves. This also needs to be taken into account when planning coastal risk-reduction strategies, and is a further reason for ensuring a diverse approach to risk reduction. Studies on the economic valuation of mangroves have estimated coastal protection to be a major portion of their total value (Marois and Mitsch 2015). Chand et al. (2013) also reported that coastline protection as the most important benefits of mangroves followed by biodiversity and protection of natural resources in ANI. Rich species diversity and high structural complexity of Andaman mangroves observed in the present also indicate that mangroves play a greater role in protection of this island ecosystem. The structural complexity is one of the determining factors for the protective role of mangroves (Spalding et al. 2014), thus mangroves with high structural complexity play a significant role in coastal conversation and management (Bosire et al. 2008). The differences in the structural development may reflect the influence of variations in tidal range, salinity gradients, texture and stability of the soil, and contribution of nutrients (Delgado et al. 2001; Lovelock et al. 2005), which is specific to each habitat. But studies to explain the relation between these habitat characteristics and forest structure are limited in India. So such studies are needed for better understanding of various ecological services offered by Indian mangroves.

Mangroves are the only marginal ecosystems which share the resources with adjoining ecosystems (Vannucci 2001). Mangroves serve as an intermediate nursery habitat and may increase the survivorship and recruitment success of commercially valuable species harvested in other ecosystems, such as coral reefs and pelagic zones (Parrish 1989, Mumby et al. 2004; Honda et al. 2013) and also affect the productivity of adjacent habitat (e.g. coral reefs and seagrass; Nagelkerken et al. 2012). Andaman Islands are bestowed with various marine and coastal ecosystems (coral reefs, seagrass etc.,), which support rich floral and faunal diversity (Rajan et al. 2013). In many sites in Andaman, mangroves are located contiguous to areas with coral reefs and seagrasses. Thus, adverse effects on mangroves could lead to serious consequences of these adjoining fragile and important ecosystems.

Conclusion

Despite the wide ecological and socioeconomic values of mangroves, they are threatened globally due to various anthropogenic activities and global climate change. The primary driver of anthropogenic mangrove loss was found to be conversion of mangroves to aquaculture and agriculture (Thomas et al. 2017). The major factors which threatened Indian mangroves are deforestation for urbanization and aquaculture and agriculture expansion, reduction in freshwater flow, marine and coastal pollution, siltation, sedimentation and excessive salinity. Compared to other mangrove habitats, mangroves of ANI are free from these anthropogenic activities. However, geomorphological changes due to the massive earthquake and subsequent tsunami on 26th December 2004 have drastically affected the mangroves of ANI. About 54 km^2 of mangroves were degraded between 2003 and 2013, and particularly between 2011 and 2013, 13 km^2 of mangrove stands have been degraded (FSI 2015). Subsequently, during 2013–2015, it was found that the mangrove extent increased by 13km^2.

Mangrove patches studied in Andaman Islands were dominated by the members of the family Rhizophoraceae and dominance of trees with 20–40 cm diameter size class and stand basal area greater than >25m^2/ha in all surveyed regions are indicative of good structural development in mangroves of the Andaman Islands. The high diversity and structural values reported in the present study and recent increase of 13 km^2 areas of mangroves in Andaman Islands (Forest Survey of India 2015) are indicative of high resilience potential and protective role of mangroves of Andaman Islands. The mangroves in Andaman Islands, in many locations, are in close proximity to the other coastal ecosystems like coral reefs and seagrasses, and in the light of the ecological interactions between these ecosystems and their associated marine biodiversity, preserving the luxuriant mangroves of these Islands assumes particular significance.

Conservation of mangroves is essential for sustaining and increasing the extent of mangroves in the islands, which are prone to many natural hazards. The ability of mangroves to reduce these coastal hazards, is influenced by the mangrove forest width and vegetation density. Generally, mangrove belts, which are several hundred meters wide and possess dense canopy are most effective in reducing hazards, and more specifically, predominance of the mangrove species with aerial roots would enable them to reduce wind and swell waves and also to withstand inundation by tsunamis. Thus, understanding the mangrove vegetation structure is always useful for their conservation and management. To safeguard the risk reduction values of mangroves, it is imperative to include mangroves restoration as a part of integrated coastal zone management plans (ICZMP).

The mangroves in India are conserved through multi-layered regulatory tools *viz.,* Indian Forest Act, 1927; Forest (Conservation) Act, 1980; and the Island Protection Zone (IPZ), 2011 notification under the Environment (Protection) Act, 1986. The EPA, 1986 and the IPZ, 2011, thereunder, provide for identifying areas with high ecological significance and prepare location-specific integrated management plans. The Andaman and Nicobar Coastal Zone Management Authority (ANCZMA) established under the IPZ, 2011 notification and the Union Territory Forest Department are responsible for implementing the various provisions of the aforesaid regulatory frameworks. So far, the conservation regimes have laid emphasis on increasing the area of mangroves and most of the restoration/rehabilitation efforts were undertaken based on inadequate species-specific information. The contemporary mangrove conservation regime advocates *"early detection and pre-emptive rehabilitation",* for successful management. And to achieve this, location-specific and species-specific information on the mangrove stands are the prerequisites (Lewis et al. 2016). The spatial data collected in this study pertaining to the overall health of the ecosystems, dominant species, etc. would aid in preparing a science-based species-specific and location-specific management plan, within the existing legal framework for mangrove conservation in India. Thus, it would help to check degradation of existing mangroves and plan effective mangrove restoration/rehabilitation strategies. The current study is be a step towards this goal and would aid in location-specific conservation planning for proper management and rejuvenation of the mangroves in Andaman Islands.

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