J. For. Res. (2019) 30(2):507–518
https://doi.org/10.1007/s11676-018-0600-2

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ORIGINAL PAPER

Structure and regeneration status of mangrove patches along the estuarine and coastal stretches of Kerala, India

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Received: 3 February 2017 / Accepted: 6 November 2017 / Published online: 23 January 2018

Abstract This study presents the structural characteristics and regeneration potential of mangrove patches in the estuarine and coastal areas of Kerala, a tropical maritime state in India. Field surveys were carried out at 46 selected sites during August 2015 to May 2016. In each site, the vegetative structure and regeneration status were assessed using the quadrat method. Altogether 219 quadrates were laid out and a total of 13 true mangrove species, belonging to 5 families and 8 genera, were recorded. The total tree density and stand basal area of the study region was 1678.08/ha and 20.33 m^2/ha respectively. The low basal areas indicate the reduced structural development in mangroves. Of the 13 tree species, *Avicennia* constitutes 56% of the total Important Value Index (IVI) and *Avicennia officinalis* represents 41% of the IVI in Kerala, followed by *Avicennia marina* (15%), *Rhizophora mucronata* (15%), *Sonneratia alba* (8%) *Rhizophora apiculata* (7%) and *Excoecaria agallocha* (7%). The diameter at breast height (DBH) in the study area revealed that 47% of the tree species came under the 1–10 cm DBH class. Total sapling and seedling density in Kerala was 2238.35 and 3232.42 individuals/ha respectively. Density of young plants (seedlings + saplings) was only 31% greater of tree density and varied from 3–63%, which indicates poor regeneration potential. The Maturity index value (MIV) and complexity index (*Ic*) value of mangroves were 18.30 and 109.81 respectively. However, the low Ic value (< 10) observed in seven out of ten coastal districts indicated poor structural development of mangroves in Kerala. Therefore, location-specific conservation and management measures, guided by the knowledge on spatial distribution and habitat requirements of mangrove varieties should be taken to preserve the mangrove diversity of Kerala.

Keywords Tree density · Complexity · Quadrat survey · Maritime · Regeneration

Project funding: The work was supported by the Society for Integrated Coastal Management (SICOM), Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi.

The online version is available at http://www.springerlink.com

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Introduction

Mangroves in India are found along the estuaries and coasts of nine Maritime States and four Union Territories. The mangrove habitat of India is broadly classified into three categories: Deltaic (Eastern Coast Mangroves); Estuarine and Backwater (Western Coast Mangroves); and Insular (Andaman and Nicobar Islands) (Mandal and Naskar 2008). Their overall cover is estimated to be 47,40 km^2, of which about 58% is along the east coast (Bay of Bengal); 29% along the west coast (Arabian Sea); and the remaining 13% on the Andaman and Nicobar Islands (FSI 2015).

Kerala has 590 km of long narrow coastal line. Mangrove vegetation occurs along the banks of estuarine water bodies and adjacent to the back water channels, in the form of a narrow continuous belt or patches. The regular tidal flooding and fresh water supply from the 41 perennial rivers create a suitable ecological environment leading to the development of mangroves on the fringes of backwaters, estuaries and creeks (Basha 1991). Kannur and Kasaragod districts have the maximum number of mangroves. The other districts are Trivandrum, Kollam, Allappuzha, Kottayam, Ernakulam, Thrissur, Kozhikode, and Malappuram, along with the three identified Ramsar sites, namely Ashtamudi, Sasthamkotta, and Vembanad.

At global level, mangroves are vanishing at fast rate with annual loss of 1–2% per year, which is 5 times greater than the global forest loss (FSI 2015). India and especially Kerala are not an exception to this trend: as of 1975, some 700 km^2 of mangroves in Kerala state have drastically shrunken to 6 km^2 by 2013 due to habitat conversion. This degradation lead to serious loss of the biodiversity and carbon stored in these ecosystems (Basha 1991).

According to the latest estimate (FSI 2015), the area under mangrove vegetation in Kerala is 9 km^2, which is an increase of 3 km^2 area compared to the 2013 assessment. However, more than 80% of the mangrove plots are in private hands. Therefore, they are under serious threat of destruction caused by anthropogenic activities (Basha 1992). Mangrove floristics of Kerala have been studied since 1678 (Van Rheede 1678–1693). However, the total number of true mangrove species in Kerala is under dispute as in other regions. Further, few attempts were made in the past to understand the structural characteristics and attributes of mangroves of Kerala (Nameer et al. 1992; Suresh Kumar and Mohan Kumar 1997; Rahees et al. 2014; Vijayan et al. 2015; Rani et al. 2016).

Management of the fast-declining mangroves requires understanding of the structural complexity (Dislich and Pivello 2002). Considering these facts, the present study was undertaken to provide a comprehensive account on the structural aspects of mangroves in Kerala.

Materials and methods

Study area and data collection methods

The study was carried out in all major mangrove habitats in Kerala and 46 sites were selected based on receptiveness, importance, and accessibility (Fig. 1). Selected sites were studied from June 2014 to March 2015. In each site, multiple line transects (100 m) were laid perpendicular to the waterfront at minimum 50 m intervals between adjacent transects. Quantitative data on mangrove vegetative

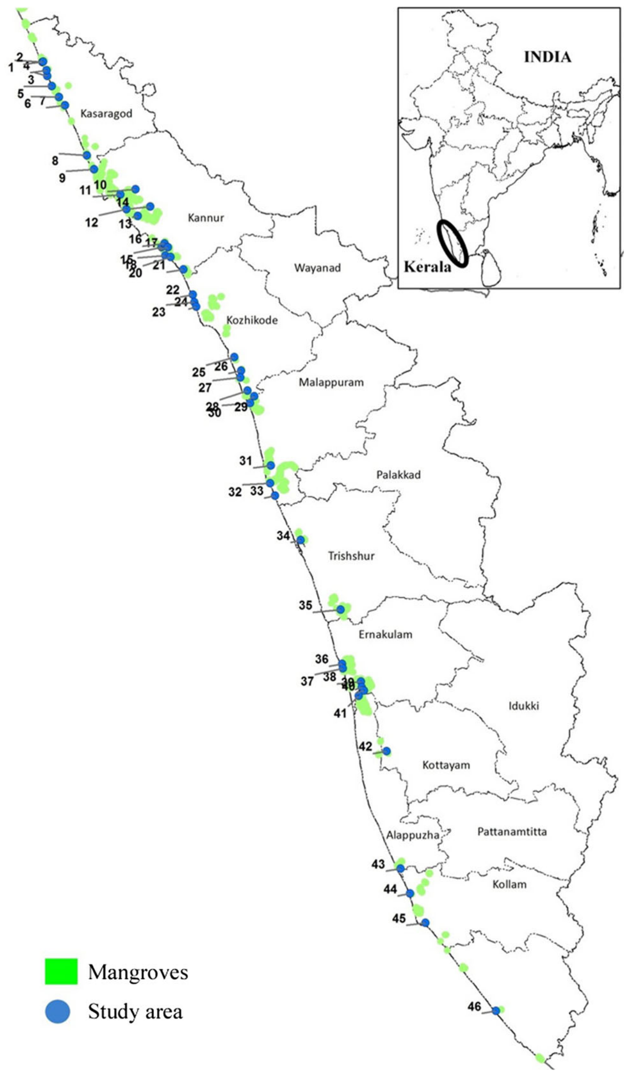

Fig. 1 Map showing the mangrove stands and the study sites in Kerala

structure was collected by laying quadrats (10 × 10 m) laid along each of the line transects at 0, 50, and 100 m. Altogether 219 quadrats were determined.

Within each plot, all mangroves were identified to variety level and counted according to three maturity categories as described by Menon (2006), namely, trees (> 4 m height), saplings (> 1 to ≤ 4 m height) and seedlings (plant ≤ 1 min height). Vegetation measurements, including tree height and DBH were noted for all trees. Species wise count data were collected for seedlings and saplings in each quadrat studied.

Data analysis

On the basis of data obtained from quadrats, the forest structural parameters—such as stem density, relative density, abundance, frequency, relative frequency, basal area, and relative basal area—were calculated for the community analysis. The importance value index (IVI) for the tree species was determined as the sum of the relative frequency, relative density, and relative dominance (Curtis 1959). In this study, relative abundance was calculated based on the basal area of individual trees using DBH. Apart from this, the following univariate measures—including Shannon–Wiener diversity index (H′) (Shannon and Weaver 1963), Margalef's species richness (d) (Margalef 1978), Pielou's evenness (J′) (Pielou 1966), Simpson dominance (D) (Simpson 1949), Complexity Index (Holdridge 1967; Pool et al. 1977), Beta diversity (β-diversity) (Whittaker 1972), Maturity Index Value (Pichi-Sermolli 1948; Nabi et al. 2012) and Jackknife estimate of species richness (Heltshe and Forrester 1983)—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). Variation patterns in community structure were evaluated using the multivariate method-grouping analysis (Cluster) based on the Bray–Curtis similarity index and ordination through non-metric multi-dimensional scaling (MDS). The aim was to detect spatial variation in the density of mangroves by using PRIMER v6 program (Clarke and Gorley 2006). The square-root transformed mangrove species density data was used for PRIMER analyses.

Results

Mangrove species diversity in Kerala

In the present study, a total of 13 mangrove tree species belonging to five families and eight genera were observed (Table 1). Among the five families, the number of species represented from the family Rhizophoraceae was the highest (7 species), followed by Acanthaceae and Sonneraticeae (2 species each). The Shannon diversity index and Pielou's evenness index for Kerala was 1.94 and 0.75 respectively, indicating high species diversity.

Among the 10 districts with mangroves in Kerala, the maximum number of species (10) was observed in Ernakulam, followed by Kasaragod, Kannur, and Malappuram (Table 1). The tree species—*R. mucronata*, *S. alba*, *A. officinalis*, *A. marina*, *R. apiculata*, and *Bruguiera cylindrica*—are almost equally abundant while *Bruguiera gymnorhiza* and *B. sexangula* have low relative abundance.

Structural features

In the present study, 15,656 plants were counted, which comprised 31.31% saplings, 45.22% seedlings, and 23.47% trees. The total tree density and stand basal area in Kerala was 1678.08/ha and 20.33 m^2/ha, respectively. Of the 13 mangrove species recorded, the IVI for *A. officinalis* was highest (41%) and the genus *Avicennia* alone constituted 56% of the IVI (Fig. 2). This shows the dominance of *Avicennia* species in Kerala. Next to *Avicennia*, *R. mucronata* constituted 15% of the IVI followed by *R. apiculata*, *S. alba*, and *E. agallocha*. All other species constituted less than 5% of IVI, which shows the rarity of the species in Kerala. Of the eight coastal districts, mangroves of Thrissur and Thiruvananthapuram were represented by single species, viz., *R. mucronata* and *S. caseolaris* respectively. Tree density and basal area were the highest at Kozhikode, followed by Kannur and Kasaragod (Fig. 3). Based on IVI, it was found that in all other mangrove areas, *Avicennia* species were dominant, except for Thiruvananthapuram and Thrissur. This showed the overall dominance of *Avicennia* species in Kerala.

The frequency of mangrove trees belonging to the 1–10 cm DBH category was the highest in Kerala. It was also evident that the number of tree stands gradually decreased with the increase in DBH classes beyond 1–10 cm (Fig. 4). This inverse "j" shaped distribution is characteristic of a balanced forest structure with uneven aged trees with the $<$ 10 cm DBH class having the maximum density and then declining as the DBH increases. The mangrove species in class intervals of 10 cm indicated that about 47% of trees occurred in 1–0 cm class, followed by 45% of trees in the 11–20 cm class. Of the 13 tree species, *R. mucronata* had the maximum representation in the 1–10 cm class, whereas *A. officinalis* had the highest in the 11–20 cm and 21–30 cm classes. Further, the individuals of *A. officinalis* were present in all of the DBH class distributions (Fig. 5).

Regeneration status

Total sapling and seedling density in entire Kerala was 2238.35 and 3232.42 individuals/ha respectively. Except for Alappuzha and Kollam, in all of the districts, seedling density was higher than that of sapling. Seedling and sapling density were highest at Kollam and lowest at Thiruvananthapuram. The density of young plants (seedling + sapling) was less than 50% of total tree density (Fig. 6a) in all the coastal districts of Kerala, except Thiruvananthapuram. Among the 13 tree species, the seedling and sapling density was highest for *A. officinalis* followed by *A. marina*, *R. apiculata*, *R. mucronata*, and *E. agallocha* (Fig. 6b).

Forest structure indices

The Shannon diversity index (H′), Simpson dominance index (D), Margalef richness index (r) and Peilou's

Table 1 District wise distribution of mangrove species in Kerala

Species	Investigation sites										Relative abundance
	Kasaragod	Kannur	Kozhikode	Malapuram	Thrissur	Ernakulum	Allappuzha	Kottayam	Kollam	TRV	
Avicennia officinalis	+	+	+	+		+	+	+	+		11.34
Avicennia marina	+	+	+	+		+	+		+		10.33
Rhizophora apiculata	+	+	+			+					9.63
Rhizophora mucronata	+	+		+	+	+					11.62
Bruguiera cylindrica	+	+	+	+		+					9.44
Bruguiera gymnorhiza	–					+					1.47
Bruguiera sexangula	–							+			2.94
Excoecaria agallocha	+	+		+		+					7.66
Aegiceras corniculatum	+										5.88
Ceriops tagal	–					+					4.41
Kandelia candel	+	+									7.89
Sonneratia caseolaris	–			+		+	+		+	+	6.01
Sonneratia alba	+	+	+	+		+					11.39
	9	8	5	7	1	10	3	2	3	1	

TRV Thiruvananthapuram

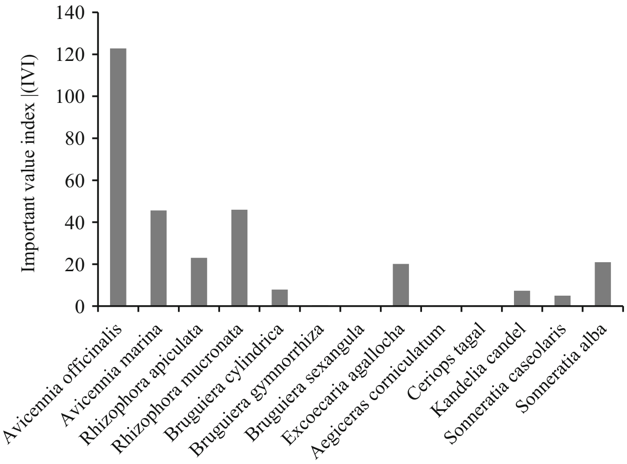

Fig. 2 Species-wise Important Value Index (IVI) of mangroves in Kerala

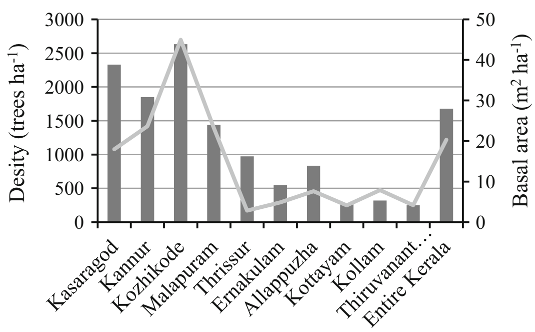

Fig. 3 District-wise tree density and basal area of mangroves in Kerala

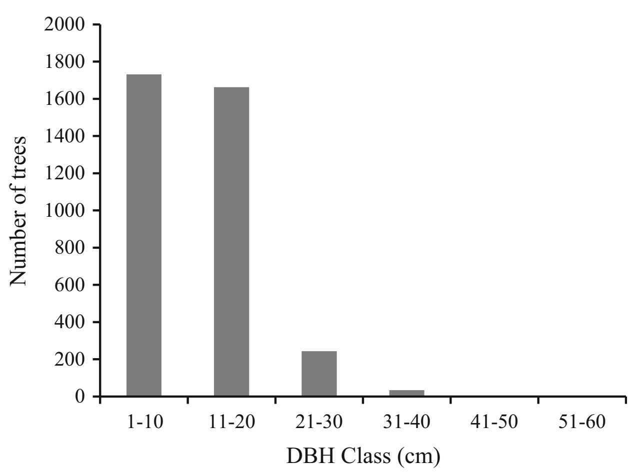

Fig. 4 Frequency distribution of mangrove trees in Kerala based on their Diameter at Breast Height (DBH)

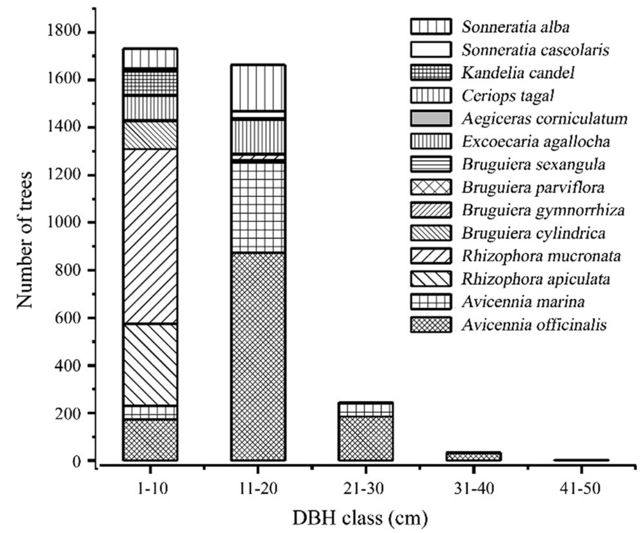

Fig. 5 Species-wise DBH class distribution of mangrove in Kerala

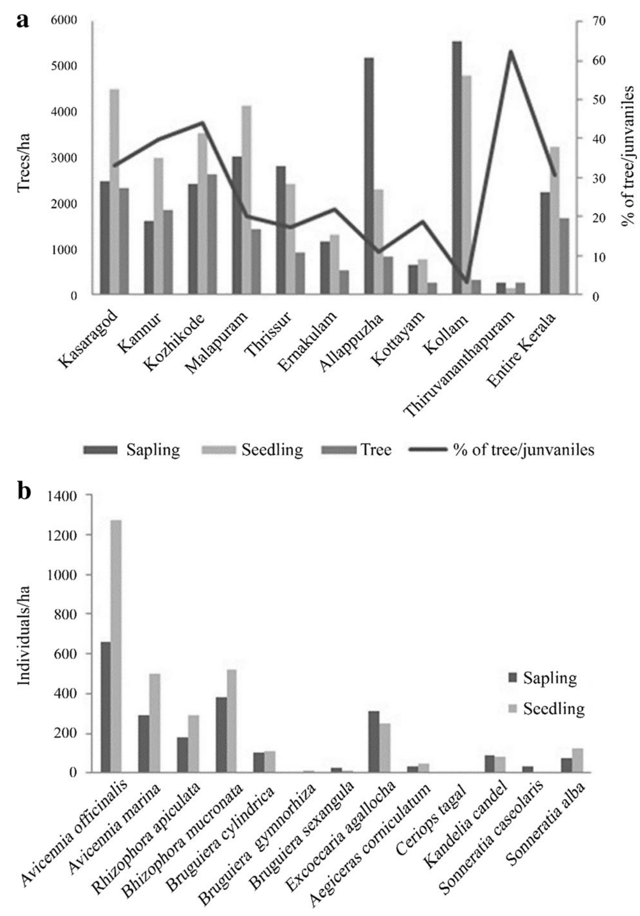

Fig. 6 Tree, sapling and seedling densities of mangroves in Kerala: **a** District-wise and **b** Species-wise

evenness index (J') were 1.94, 0.20, 1.46 and 0.75, respectively (Table 2). While the species richness index was high at Ernakulam (1.76), evenness and Shannon diversity index were low, indicating unequal abundance of certain mangrove species in Ernakulam. In contrast, the Shannon diversity and evenness index was high at Allappuzha (2.12 and 1.34, respectively), while the species richness was low.

Table 2 Forest structure indices of mangroves in Kerala

Forest structure indices	Investigation sites										Entire Kerala
	KAS	KAN	KOZ	MAL	TRI	ERN	ALP	KOT	KOL	TRV	
Jack Knife index	10.95	8.00	5.00	8.87	1.00	10.97	3.00	2.67	3.00	1.00	15.99
Complexity index	162.57	0.00	210.89	81.93	5.67	9.97	10.13	1.74	5.02	0.87	109.81
Simpsons measure of evenness	0.36	0.34	0.40	0.53	1.38	0.28	0.97	0.84	0.82	0.78	0.31
Simpsons index	0.19	0.20	0.28	0.28	0.28	0.46	0.14	0.55	0.18	0.64	0.20
Shannon Weiner diversity index	1.81	1.82	1.58	1.69	1.52	1.19	2.12	0.93	1.89	0.54	1.94
Margalef richness Index	1.16	0.96	0.61	1.12	0.00	1.76	0.51	0.48	0.58	0.00	1.46
Pielous evenness index	0.82	0.87	0.98	0.87	0.00	0.51	1.93	1.34	1.72	0.00	0.75
Maturity index value	38.24	31.41	41.54	23.81	42.86	22.67	50.00	50.00	33.33	100.00	18.30

KAS Kasaragod, *KAN* Kannur, *KOZ* Kozhikode, *MAL* Malapuram, *TRI* Thrissur, *KRN* Ernakulum, *ALP* Allappuzha, *KOT* Kottayam, *KOL* Kollam, *TRV* Thiruvananthapuram

After comparing diversity indices, it was apparent that mangroves in Kannur were the most diverse, followed by Kasaragod, Malappuram, and Ernakulam. The Maturity Index Value (MIV) and Complexity Index (*Ic*) value of mangroves of Kerala were 18.30 and 109.81, respectively. MIV was highest in Thiruvananthapuram district (100), while *Ic* was the highest in Kozhikode (210.89). The estimated Jack knife index was 15.99 (Table 2). The mangroves areas in Kerala were found to have *Ic* value of < 14 (Table 2), except in the Kasaragod, Kozhikode, and Malappuram districts that showed the existence of stress and disturbance in these areas. The MIV of the Kerala Mangroves ranged from 23.81 to 50.00, which was less than the maximum value (*i.e.* 100), depicting their low degree of maturity.

Bray–Curtis cluster analysis, based on the species composition and IVI (Fig. 7), grouped ten districts of Kerala into three major clusters. Thiruvananthapuram, Thrissur, and Kottayam are grouped into one cluster as they represented by one or two species, whereas Allappuzha and Kollam are grouped into another cluster, having three species each. Districts having high species richness, e.g., Kozhikode, Kasaragod, Ernakulam, and Malappuram, were grouped in one cluster. Based on the species cluster and the accompanying MDS (Fig. 8a, b), the abundance and distribution of mangroves species in Kerala could be divided into five groups, having 20% similarity: (1) Group 1 included *A. officinalis* and *A. marina,* which were widely represented in the Kerala mangroves and constitute the major portion (about 50%) of the IVI, (2) Group 2 included *R. mucronata*, *R. apiculata*, *B. cylindrica*, *E. agallocha* and *S. alba*, and these species were found in few districts of Kerala with equal abundance, (3) Group 3 included *Aegiceras corniculatum* and *Kandelia candel*, (4) Group 4 included *B. gymnorhiza* and *Ceriops tagal*, whereas Group 5 had only *B. sexangula*, (5) Species in Group 3–5 had restricted distribution and low relative abundance.

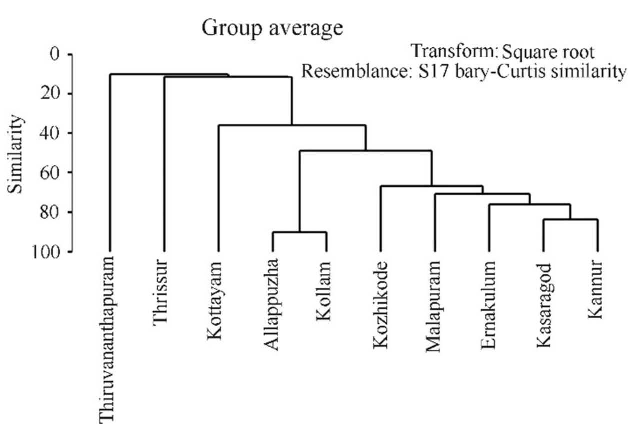

Fig. 7 Dendrogram showing similarity among the study sites in Kerala

Discussion

Species diversity

The earliest reference on mangrove floristics in Kerala (Van Rheede 1678–1693) reported eight mangrove species: *A. corniculatum*, *A. officinalis*, *E. agallocha*, *K. candel*, *Lumnitzera racemosa*, *Rhizophora cyclindrica* (= *R. apiculata*), and *R. mucronata.* Subsequently Drury (1864) had described a few more plants, apart from the ones listed by Van Rheede (1678–1693) namely, *Eriops candolleanus* (= *C. tagal*) and *Bruguiera eriopetala* (= *Bruguiera sexangula*).

Later Beddome (1866), Hooker (1872), Bourdillon (1908), Rama Rao (1914) and Gamble and Fischer (1915–1935) described the distribution of mangrove species as part of their forest floral assessment. Consequently, there were many studies on the occurrence of mangrove flora along the Kerala coasts (Troup 1921; Govinda-Menon 1930; Erlanson

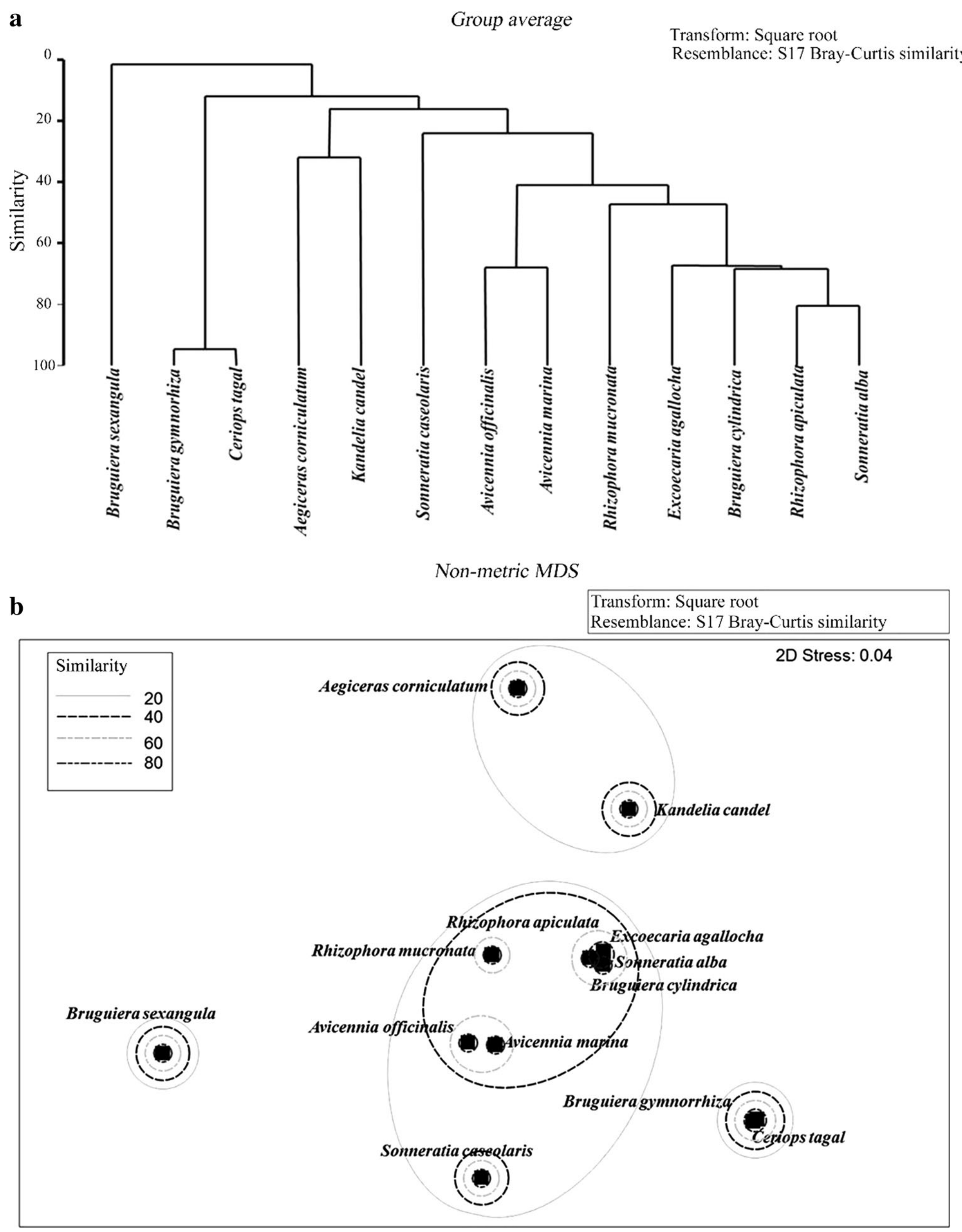

Fig. 8 **a** Hierarchical clustering (Bray–Curtis similarity) of mangrove species based on the density and IVI, **b** nMDS ordination of mangrove species based on the density and IVI

1936; Mudailarm and Kamath 1954; Thomas 1962; Rao and Sastry 1974; Blasco 1975; Kurian 1980; Ramachandran et al. 1986; Ramachandran and Mohanan 1987). However, their efforts did not provide the comprehensive account on floristics and distribution of mangroves in Kerala.

Ramachandran et al. (1986) made the first inventory of the mangrove flora, mapped them along the entire coast of Kerala and reported 18 true mangrove species.That said, the distributional status of true mangrove species in Kerala was not provided. Later, Basha (Basha 1991, 1992) provided the comprehensive account on mangrove flora of Kerala, listing 18 true mangrove species and also their status and distribution in entire Kerala coast.

In the recent past, Anupama and Sivadasan (2004) reported 15 true mangrove species and Kathiresan (2008) reported 19 true mangroves species. Vidyasagaran and Madhusoodanan (2014) reported 15 true mangrove species from Kerala. The variation in mangrove floristics of Kerala in earlier studies could be attributed to the uncertainty in the classification schemes of mangroves. As per the recent review on mangrove floristics, of India based the classification of Polidoro et al. (2010), a total of 19 species belonging to 12 genera and 8 families have been recognized as true mangroves species in Kerala (Ragavan et al. 2016).

The total number of species recorded in the present study does not include *Acanthus* species, *L. racemosa*, *E.*

agallocha and *Acrostichum* species. As the current study was designed to provide the structural characteristics of tree mangrove species, the mangrove associate, *Acrostichum* species were excluded; *L. racemosa* and *E. agallocha,* which had a very restricted distribution in Kerala, were not found in this study. The reduction in species number could be attributed to the intensity of research efforts, sampling locations, and species considerations (Van Nguyen et al. 2013; Whitmore 1988).

Vegetative structure

Stand density and tree height are important for biomass and coastal protection functions, as well as resilience ability to absorb or recover from environmental impacts (Kathiresan et al. 2016). The tree density (250–2634.60/ha) and basal area (2.84–44.96 m^2 ha^{-1}) of mangroves of Kerala observed in this study were similar to earlier studies (*e.g.* Nameer et al. 1992; Suresh Kumar and Mohan Kumar 1997; Rahees et al. 2014; Vijayan et al. 2015). However, Rani et al. (2016) reported high density (7680–11,760/ha) and basal area (0.16–94.32 m^2 ha^{-1}) from Cochin mangroves, which could be attributed to the inclusion of *Acanthus* and *Acrostichum* species.

Basal area is an indicator for measuring forest-stand development and understanding species population, biomass and productivity in response to stress factors (Twilley 1998). Pristine mangrove forests with minimal impacts 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 area 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). The total stand basal area in mangroves of Kerala was 20.33 m^2 ha^{-1}, which indicated the secondary succession.

Among the coastal districts, the basal area of mangroves in Kozhikode was > 25 m^2 ha^{-1}, indicating their pristine nature. Kannur, Kasaragod, and Malappuram had basal areas around 15 m^2/ha, which showed secondary succession, whereas all other mangrove areas in Kerala were found to have a basal area > 10 m^2/ha, indicating the distributed nature of mangrove forest with low structural development.

Further, more than 50% of basal areas and IVI were represented by *Avicennia* species, which showed the dominance of this species in mangroves of Kerala as already reported by various researchers (Nameer et al. 1992; Suresh Kumar and Mohan Kumar 1997; Rahees et al. 2014; Vijayan et al. 2015; Rani et al. 2016). Usually the structural development of the pioneer species of mangrove ecosystem is considered for checking the maturity of that forest and after considering the overall structural data (Pellegrini et al. 2009).

It was observed that the pioneer species *A. officinalis* having mature structural development in most of the mangrove areas in Kerala. The structural complexity in forest stands is a function of tree species richness, among other variables (Holdridge et al. 1971; Kairo et al. 2002; Bosire et al. 2003). But the monospecies dominance results in the reduction of structural complexity and ecosystem services. *Ic* is often used for quantitative description of the structural complexity of the tropical vegetation (Pool et al. 1977). The estimated *Ic* values and MIV in Kerala showed some similarity with earlier studies (Pool et al. 1977; Fromard et al. 1998; Amarasinghe and Balasubrananiam 1992; Upadhyay and Mishra 2014; Joshi and Ghose 2014). Singh et al. (1990) and Singh and Odaki (2004) reported *Ic* values of 6.9–14.1 for disturbed and 87.1–260 for undisturbed mangroves of Andaman Islands of India.

In the present study, the *Ic* values ranged from 0.87 to 210.89 and for the entire Kerala state, it was 109.81. This indicated that the mangroves patches along the Kerala coast are generally undisturbed, but with regional exceptions. However, the *Ic* value was less than 10 in seven coastal districts, except Kannur, Kasaragod and Malappuram, indicating low structural development and prevalence of disturbances in these mangrove stands.

Earlier studies also reported the degraded nature of mangroves of Kerala (Basha 1991, 1992; Nameer et al. 1992; Suresh Kumar and Mohan Kumar 1997; Rahees et al. 2014; Vijayan et al. 2015; Rani et al. 2016; Khaleel 2005). All of the mangrove areas, except Thiruvananthapuram, had low MIVs, which indicated the absence of matured forest. Thus, the mangrove habitats in Kerala illustrate the presence of uneven, aged mixed mangrove forest with well and low structural development based on the overall stand basal area.

The density and stand basal area values from the Kerala mangroves were comparable with the mangrove forests in India and other parts of the world (Table 3). While the tree density in Kerala (250–2634.60 trees/ha) was lower than that found in Thailand (Chasang 1984; Macintosh et al. 2002), Papua New Guinea (Robertson et al. 1991; Johnstone 1983), Belizean coast, Central America (Murray et al. 2003) and Indonesia (Hinrichs et al. 2009), it was higher than that in Srilanka (Kala Oya estuary) and Malaysia (Kelantan delta) (Table 3).

Within India, the tree density of Kerala mangroves was lower than the mangroves of Gujarat, Andhra Pradesh, Odisha, and West Bengal, and higher than that of Pichavaram and ANI (Table 3). The stand basal area in the Kerala mangroves showed similarity with Kala oya estuary (Srilanka), Keltan delta (Malaysia) and Zambezi River Delta (Brazil) and higher than the other mangrove habitats of India (Table 3).

Table 3 Comparison of mangrove tree density and basal area in different mangrove forests of the world

Mangrove forest	Country/region	Density (trees ha^{-1})	Basal area (m^2 ha^{-1})	References
Kala Oya estuary	Sri Lanka	10–528	27.10–48.25	Perera et al. (2013)
Kelantan delta	Peninsular Malaysia	790–1360	1.4–49	Satyanarayana et al. (2010)
Sibuti mangrove forest	Malaysia	1600–2340	171.10–201.83	Shah et al. (2015)
Bocas del Toro archipelago	Panama	4730–33,570	6.8–30.1	Lovelock et al. (2005)
Ceará state	Brazil		0.47–2.9	Maia and Coutinho (2012)
Zambezi river delta	Brazil	158–6000	1.2–40.8	Trettin et al. (2016)
Segara Anakan lagoon	Indonesia	10–2880	0.02–10.28	Hinrichs et al. (2009)
Samar Island	Philippines	1500–3000	5.0–22.78	Mendoza and Alura (2001)
Mundra coast and Kharo creek	Gujarat, India	1820–4325	–	Sawale and Thivakaran (2013)
Coringa mangrove forest	Andhra Pradesh, India	90–17,310	0.01–120	Satyanarayana et al. (2009)
Coringa mangrove forest	Andhra Pradesh, India	6140	–	Azariah et al. (1992)
Kakinada Bay	Andhra Pradesh, India	470–17,310	10–109	Satyanarayana et al. (2002)
Krishna mangroves	Andhra Pradesh, India	734–5009		Venkanna and Narasimha Rao (1993)
Godavari mangroves	Andhra Pradesh, India	874–6895		Venkanna and Narasimha Rao (1993)
Bhitarkanika	Odisha, India	2012–3586	3.17–7.55	Upadhyay and Mishra (2014)
Lothian Island	West Bengal, India	912–7031	4.2–19.2	Joshi and Ghose (2003)
Lothian Island	West Bengal, India	4723–23,751	4.9–20.3	Joshi and Ghose (2014)
Andaman and Nicobar Islands	India	487–2383	–	Ragavan et al. (2015)
Pichavaram	Tamil Nadu, India	1641		Kathiresan et al. (2016)
Kollam mangroves	Kerala, India	267–3760	1.58—29.70	Vijayan et al. (2015)
Cochin estuary	Kerala, India	7680–11,760	0.16–94.32	Rani et al. (2016)
Puduvyppu mangroves	Kerala, India	11–700	0.1–2.0	Nameer et al. (1992)
Puduvyppu mangroves	Kerala, India	74–2834	0.16–10.40	Suresh Kumar and Mohan Kumar (1997)
Kadalundi mangroves	Kerala, India	107–5014	0.30–46.69	Rahees et al. (2014)
Entire Kerala	India	250–2636	2.84–44.96	Present study

The wide variation in density and basal areas of different studies could be partially attributed to the variation in the classification criteria of mangroves. For example, Satyanarayana et al. (2002) classified plants < 4 m height as trees, while Narasimha Rao (2012) measured the DBH just above the ground level, as, in his study area (Andhra Pradesh), larger tree species were less. Further, most forest structure assessments were concentrated only in few areas in the states and the inclusion of coastal vegetation and marsh plant also contributed to the exaggerated values.

Regeneration status

The density and abundance of saplings and seedlings indicate the regeneration potential (Twilley 1995; Pallardy 2008). Seedling recruitment and survivorship principally drive the population growth (Burns and Ogden 1985; Krauss et al. 2008) and thus determine the quality of crop and productivity of forest stands (Srivastava and Bal 1984). Regeneration potential of mangroves is usually measured using sapling and seedling abundance data (Ashton and Macintosh 2002). Good regeneration potential is determined based on two criteria: (1) if the total number of saplings and seedlings is greater than 50% of mature trees per hectare (Gan 1995) and (2) if a minimum of 2500 seedlings are present in one-hectare area of the forest (Srivastava and Bal 1984). The first criterion factors the density of mature trees responsible for seedling production, while the second criterion does not.

In the present study, the density of young plants (seedlings + saplings) was only 30.67% higher than that of tree density, which suggested that the mangroves in Kerala had poor regeneration potential (as per the first criterion, above). On the contrary, the seedling density was > 2500 individuals/ha in Kasaragod, Kannur, Kozhikode, and Malappuram and the mean seedling density was 2701 ± 1600, which suggested good regeneration potential of the mangroves in Kerala (as per the second criterion, above). Further, the occurrence of a large proportion of saplings over seedlings also implied the high growth rate of seedlings. However, as the density of young plants represented < 50% of tree density in all the coastal districts of Kerala except Thiruvananthapuram, it is concluded that the mangroves in Kerala possessed poor regeneration potential.

Conclusions

Mangroves in Kerala represent 0.19% of the total mangroves of India, with total areas of just 9 square km^2, but they represent 41% of the true mangrove species in India. In the present study, 13 mangrove species, belonging to 5 families and 8 genera were recorded from Kerala and it was found that mangroves in Kerala varied in diversity, density, and structural development.

The structural characteristics of the mangrove forest revealed the presence of uneven, aged mixed mangrove forest. Considering the overall structural data, it could be concluded that the mangroves in Kasaragod, Kannur, Kozhikode, and Malappuram have high species diversity and considerable structural development. Though the mangroves of Ernakulam had high species richness, monospecies dominace and lows basal area indicated poor structural development and uneven species abundances. Mangroves in other districts have low species diversity and structural development. Further the density of young plants less than 50% of tree density, suggested that the mangroves in Kerala had poor regeneration potential.

The mangrove ecosystems are threatened globally due to various anthropogenic activities and climate change. Further, the species diversity of Indian mangroves is under constant flux due to both natural (e.g. erosion, aggradations) and anthropogenic forces, possibly leading to changes in floristic composition and local extinction of some species. Forest structure determines biodiversity and the ecosystem function and is closely correlated with stress, but in the Indian context, studies on mangrove forest structure are very limited. Since mangroves are species poor compared to other tropical ecosystems, the knowledge on species composition and structural characteristics of mangrove forest in an area are essential for the better management of mangroves.

So far, the conservation regimes in most countries including India have laid emphasis on increasing the area of mangroves and most of the restoration/rehabilitation efforts are undertaken based on inadequate species-specific information. The contemporary mangrove conservation regime on global scale 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 data provided in this study would be a step toward this goal and aid in location-specific conservation planning for proper management and rejuvenation of the mangroves in Kerala.

Acknowledgements The study was undertaken as a part of a national research project, "Delineation of ecologically sensitive areas (ESA) and critically vulnerable coastal areas (CVCA) along the coast of India," supported by the Society for Integrated Coastal Management (SICOM), Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India, New Delhi. The framework for the study was developed by National Centre for Sustainable Coastal Management, MoEFCC, Chennai and the field studies were undertaken by ICAR-Central Marine Fisheries Research Institute, Kochi, Kerala.

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