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Structural characteristics of mangrove forest of Kachchh, Gujarat

Amol Kumar Sawale[1] and G.A.Thivakaran*
Gujarat Institute of Desert Ecology, PB.No.83, Mundra Road, Bhuj-370 001, Kachchh, Gujarat
[1]Horticulture Department, Adani Port and Special Economic Zone, Navinal-Mundra, Kachchh, Gujarat

*Correspondence e-mail: ga_thiva@rediffmail.com

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Original Article

Abstract

Mangrove vegetation structure and density of younger classes (<1 m) was investigated in two mangrove stands namely Mundra and Kharo at Kachchh coast, Gujarat, India. Vegetation structure was studied in terms of density, mature tree height, Girth at Breast Height (GBH) and Canopy Index (CI). At Mundra, mature tree density ranged between 1820 and 4325/ha whereas the height and GBH range was 1 to 6.7 m and 3 to 112 cm, respectively. In Kharo station, mature tree density range was 1084 to 3559/ha. Height and GBH in this station ranged between 1 to 7.8 m and 5 to 112 cm. The observed biological parameters were analyzed for different size classes also in order to understand stand structure and age classes. Altogether, 3284 mature trees in 107 quadrates and 37 transects were studied in these two stations. Structural attributes of Kachchh mangroves was found inferior to other mangrove formations of India probably due to aridity of the coastal belt.

Keywords: *Kachchh, mangroves, vegetation structure, aridity, Avicennia marina.*

Introduction

Mangroves are taxonomically diverse assemblages of wood plant communities belonging to several unrelated angiosperm families with special adaptations to saline conditions (De Silva and Balasubramanium, 1985; Tomlinson, 1986). Though mangrove ecosystems occur in tropical as well as subtropical region, the floristically richest mangroves are found in tropical Southeast Asia (Linden and Jernelov, 1980). Mangrove forests have been estimated to have occupied 75% of the tropical coast worldwide (McGill, 1959; Chapman, 1976), but anthropogenic pressures have reduced the global range of these forests to less than 50% of the original total cover (WCMC, 1994; Spalding *et al.*, 1997). About 117 countries have mangrove resources covering an area of 1,90,000 to 2,40,000 km^2 (Upadhyay *et al.*, 2002). Kachchh mangroves cover an area of 775 sq.km (FSI, 2009). It has been reported that the pressure on Kachchh mangrove is through grazing, fodder collection, erosion of shoreline and industrial impact (Upadhyay *et al.*, 2002). In the recent years, pressure arising due to developmental activities has been severe on Kachchh mangroves (Thivakaran, 2011). Loss of mangrove through human interventions has been documented from many parts of the world as a result of land reclamation, grazing of live stock, cutting of timber (Walsh, 1974; Hussein, 1995; Semesi, 1998), salt pond construction (Terchunian *et al.,* 1986), oil spills (Ellison and Farnsworth, 1992) mining (Lewis, 1990; Wolanski, 1992) and dumping of rubbish (Saenger *et al.*, 1983). Reduction in the abundance of mangroves has usually been interpreted in terms of loss of biodiversity or fisheries resources (GESAMP, 1991; Marshall, 1994).

Since mangroves become increasingly threatened by various human impacts (ITTO, 1993, Pernetta, 1993; IUCN, 1996; Farnsworth and Jackes, 1987), there is a need to investigate the mangrove vegetation with the purpose of predicting changes in the future. This is especially important in Kachchh which harbors the largest mangrove forest in the west coast of India with 1046 sq.km of mangroves (FSI, 2009). On the other hand, Kachchh coast, of late is witnessing aggressive industrial development like ports, jetties, thermal power plants and cement industries which are located right amidst mangroves or in its close vicinity, necessitating increased attention to its conservation. This study was undertaken with the objective to document the present status of Kachchh mangroves in terms of its vegetation structure and regeneration potential which will help the managers for conservation in future in the light of ongoing development.

Material and methods

Vegetation parameters analyzed include mature tree density, Girth at Breast Height (GBH) and canopy cover (as an index). In addition to these parameters, the stand dynamics was further investigated by measuring two age classes namely regeneration and recruitment class in order to gain an insight into the stand dynamics. Based on the data gathered, status of the mangroves has been analyzed.

Mangrove vegetation structure in both Mundra coast and Kharo creek sites were studied using line intercept transect method (Kershaw, 1973; Mueller-Dombois and Ellenberg, 1974). Locations in each site were chosen based on an initial reconnaissance survey and consultation of Survey of India toposheets. At Mundra coast, mangrove formations at Navinal creek (NC), Bocha creek (BC), Abban creek (AC) and Baradimatha creek (BMC) were investigated. Along Kharo creek, six major formations, which are numbered from I to IV were studied. Altogether, 57 quadrates in 20 transects covering 1716 trees were studied in Mundra mangroves whereas in Kharo, 50 quadrates in 17 transects covering 1568 trees in total were sampled for mangrove structural attributes. Mangrove studies were carried out during low tide when all the stands are well exposed. For each stand studied, GPS reading was noted down for future references.

In each station, transect positions were chosen randomly perpendicular to the waterfront and generally three plots of 10×10 m were laid. Distance between quadrates in each transect was determined based on the width of the mangrove stand from low to high tide levels. In each plot, the total number of mature trees was counted. For all trees in the plot, tree height and girth at breast height (GBH) were measured using ranging rods and measuring tapes. Similarly, canopy length and width were measured and multiplied to calculate canopy index (CI). Girth at Breast Height (GBH) of all mature trees taller than 1 m was measured. Within each 10 x 10 m larger plot, subplots of 1×1 m and 2×2 m were laid randomly to enumerate two types of younger classes namely regeneration and recruitment classes. Seedlings that are germinating saplings which are less than 50 cm tall were considered as regeneration class and the recruitment class were well established saplings which are more than 50 cm but less than 1 m. Density of mature trees, regeneration and recruitment class for each station was expressed as number per hectare (No/ha). Tree height and GBH data were segregated into different size classes to study their frequency of occurrence for all the three species since *Rhizophora mucronata* and *Ceriops tagal* was recorded only in three stations out of ten.

Results

Overall structural characters of the mangroves of Mundra and Kharo stations like density, tree height, GBH and canopy Index are given in Tables 1 and 2. The ratio of the regeneration, recruitment and mature tree classes are shown in Tables 3 and 4.

Tree density

Pooled data of mangrove tree density at Mundra stations showed occurrence of highest density of 4325/ha in Baradimatha stand followed by mangroves of Abban creek which recorded a density of 3633 trees/ha. Lowest mature tree density of 1820/ha was recorded at Navinal creek stand. In Bocha, the density was moderate with 2526/ha (Table 1). In all the creeks studied, density was more in the mouth region. Density wise, Bharadimatha seems to be the youngest stand with the highest density. Similarly, in Navinal the density is lowest and trees are more spaced with high GBH.

In Kharo creek stations, highest density of 3559 trees/ha was recorded at Stn. III followed by Stn I (2995 no/ha), IV (2926/ha) and VI (2806 ha) (Table 2). Both at Mundra and Kharo mangroves tree density was observed to be the highest in low and mid tide level and in most of the cases the forest became scrubby with stunted trees.

Tree height

In Mundra, tree height in the 4 stations showed significant variation and ranged from 1 m to 6.7 m among all stations studied (Table 1). An overall mean height of 2.24 m was recorded. Highest variation of 1 to 6.7 m was recorded at Navinal mangroves (NC) and lowest variation of 1 to 5 m at Abban creek (AC). In the rest of the patches, variation in tree height was 1-5.5 m in Bocha creek (BC) and 1- 6 m at

Table 1. Structural attributes of mangroves in Mundra

Stations	Density-no/ha	Tree Height-m				GBH-cm				Canopy Index			
		Min	Max	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD
Abban (AC)	3633	1	5	2.09	±0.78	112	3	19.29	±11.89	25	0.04	3.29	±3.49
Bocha (BC)	2526	1	5.5	2.43	±0.87	110	3	25.22	±18.73	36	0.04	5.19	±5.78
Novinal (NC)	1820	1	6.7	2.32	±0.99	97	3	23.79	±16.94	36	0.25	4.69	±5.53
Baradi (BMC)	4325	1	6	2.13	±3.57	42	2	13.46	±6.73	22.5	0.01	1.89	±2.72
Mean	3076.25	5.8	0.95	2.24	±1.55	90.25	2	20.44	±13.57	29.87	0.075	3.76	±4.38

Baradimatha creek (BMC). Considering overall station-wise mean, trees were considerably taller at Bocha creek with 2.43 m while it was shorter at Abban with a mean height of 2.09 m. Similar to density, mangrove patches towards high tide levels are stunted with reduced height.

In Mundra mangroves, segregation of tree heights into different frequency classes of 0.4 m interval showed that higher number of trees were in the height classes 1.6-1.9 and ≤1.5 m, constituting 25.3% and 29.9‰, respectively (Fig. 1). This was followed by 16.51% of trees in 2-2.3 m height class and 10.45% trees in 2.4-2.7 m height class. Tallest trees exceeding 4 m were only 2.93% of the total trees (1716) measured. Similarly, trees exceeding 6 m height was very few and were recorded only in Baradimatha and Navinal creek mangroves. Abban and Baradimatha mangrove stands had largest proportion of younger classes in the size class of 1.5 m and 1.6 – 1.9 m whereas in other mangrove stands it was proportionately lesser. Hence, mangrove stands of Abban and Baradimatha seem younger and being in a development stage towards climax community.

At Kharo mangroves, tree height in all the 6 stations showed significant variation and ranged from 1 to 7.8 m among all stations with an overall mean of 2.43 m (Table 2). Highest variation of 1 to 7.8 m was recorded at Stn III mangroves and lowest variation of 1 to 4.1 m at Stn VI. Considering station wise means, trees were considerably taller at Stn II with a mean height of 3.03 m where minimum mature tree density of 1084/ha was recorded. Generally, tree height was shorter at Stn VI with a mean height of 2.21 m. Similar to Mundra mangroves, the pattern of reduced height with increased GBH due to less tidal flushing could be seen in Kharo mangroves also.

In Kharo, segregation of tree heights into different classes at 0.5 m interval showed that more trees were in the height classes 1.5-2 m and 2-2.5 m, constituting 29.71 % and 21.04%, respectively (Fig. 1). This was followed by 17.47% of trees in 1-1.5 m height class and 11.03% trees in 2.5-3 m height classes. Tallest trees higher than 4 m were numbering 72, constituting 4.5% of the total trees of 1568 studied. Trees more than 5 m height were recorded only in Stns I, II, III and IV. These stations had largest proportion of younger classes

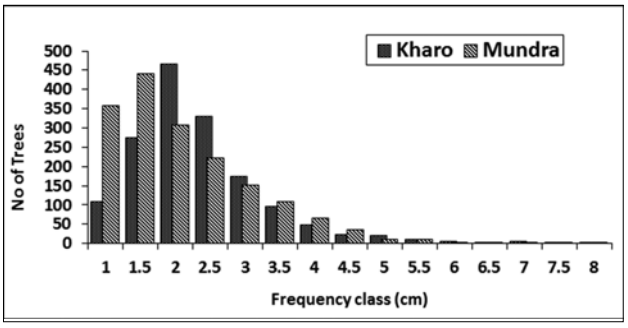

Fig. 1 Frequency classes of mature tree heights in Mundra and Kharo mangroves

Table 2. Structural attributes of mangroves of Kharo creek

Stations	Density- No/ha	Tree Height- m				GBH-cm				Canopy Index			
		Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
I	2995	1	4.7	2.44	0.77	5	112	27.2	14.32	1.1	16	2.56	3.21
II	1084	1.5	5.8	3.03	1.21	14	81	35.65	13.87	1.6	27	6.93	7.16
III	3559	1	7.8	2.26	1.18	5	72	21	13.56	1	87	6.44	9.45
IV	2926	1	5.4	2.3	1.1	6	61	22	12.32	1	91	7.2	8.4
V	2701	1	5.8	2.39	1.15	6	52	24.4	11	1	23	5.2	4.1
VI	2806	1	4.1	2.21	1	5	81	24.5	13.11	1	26	5.3	4.21
Average	2679			2.438		6.833	76.5	25.79		1.117	45		

in the size class of 1.5 m and 1.6 – 1.9 m whereas in other mangrove stands it was proportionately lesser.

Tree Girth (Girth at Breast Height-GBH)

In Mundia, mean values of GBH at different mangrove stands ranged between 13.46 and 25.22 cm (Table 1). The minimum and maximum GBH of the trees varied from 3 to 112 cm at Abban, 3 to 110 cm at Bocha, 3 to 97cm at Navinal and 2 to 42cm at Baradimatha creek. Trees with maximum mean GBH of 25.22 cm were recorded at Bocha creek mangroves and minimum of 13.46 cm was at Baradimatha creek.

Overall segregation of GBH in all mangrove stands in class intervals of 5 cm indicated that 44.46% of trees occurred in 6 to 15 cm category followed by 25.4 % of trees in 16.25 cm; 14.16% of trees in 26 to 35 cm category (Fig. 2). Trees with GBH of >65 cm constituted only 1.8 % and were recorded only in Bocha and Navinal creeks, whereas it was totally absent in other creeks. Generally, percentage of trees more than 45 cm GBH was less, recording only 5.24 % of total trees.

Among Kharo mangroves, minimum GBH across stations were 5 cm at Stns I, III and VI and maximum was 112 cm at Stn I. Mean GBH values at different mangrove stands

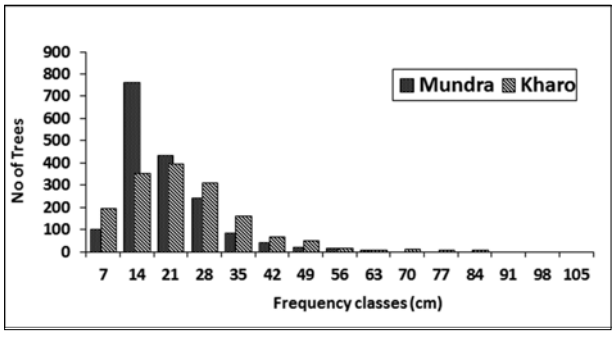

Fig.2 GBH frequency classes of mature trees at Mundra and Kharo mangroves

ranged between 21 (Stn. III) and 35.65 cm (Stn II) (Table 2). Mangroves at Stn III which recorded highest density (3559 no/ha) with lowest GBH (21 cm) were the youngest stand among all the stations studied. In contrast, mangrove stand of Stn II were older and seems to have reached its maximum density and climax as shown by its low density and high GBH values.

Overall segregation of GBH of Kharo creek mangroves at class intervals of 7 cm indicated that 25.19% of trees occurred in 15 to 21 cm class followed by 22.4 % of trees in 8 to 14 cm; 19.64% of trees in 22 to 28 cm; 12.4% of trees at >7 cm category (Fig. 2). Trees with GBH of >63 cm constituted only 1.6 % of all the trees sampled and were recorded only in Stns I to III whereas it was totally absent in other stations. Out of 1568 trees, only 6% of trees were with >42 cm GBH. The results suggested that the stands at Stns II and I were the oldest among all the stands studied.

Canopy index

Canopy Index is the value obtained by multiplying the length and breadth of the tree canopy. The mean, maximum and minimum canopy Index in Mundra mangrove stands ranged between 1.89 and 5.19 at Baradimatha and Bocha creek stands, respectively (Table 1). Minimum and maximum Canopy Indices at different stations ranged between 0.04-25 at Abban; 0.04-36 at Bocha; 0.25-36 at Novinal and 0.01-22.5 at Baradimatha. The mean canopy index ranged in the order of BMC>AC>NC>BC. Trees with the maximum Canopy Index (36) were recorded from Bocha and Navinal whereas the lowest canopy index (0.01) was recorded at Baradimatha. Generally, canopy cover was more at Navinal and Bocha creek mangroves whereas it was less at BMC and AC mangrove stands.

Among different size classes of canopy, frequency was more at 2–4 class contributing 40.9% of the total trees (Fig. 3). This was followed by the class of 1 m class contributing 36.2% of the total trees studied. Canopy class in the range of 5-7 contributed only 8.97% and 8-10 class contributed a minimum of 6.4% only. Canopy classes more than 14 contributed only 4.2% of the total trees measured.

Mean canopy Index in Kharo creek mangrove stands ranged between 2.56 and 7.2 at Stn I and Stn IV, respectively (Table. 2). Canopy indices ranged between 1.1-16 (Avg- 2.56); 1.6-27 (Avg- 6.93); 1- 87 (Avg-6.44) 1-91 (Avg-7.2); 1-23 (Avg-5.2) and 1-26 (Avg-5.3) at Stns I to VI. The mean canopy index decreased in the order of stns. IV>II >III>VI >V >I.

Frequency classes of canopy indices at the interval of 4 m revealed that majority of the tree canopies (45%) were at 1-5

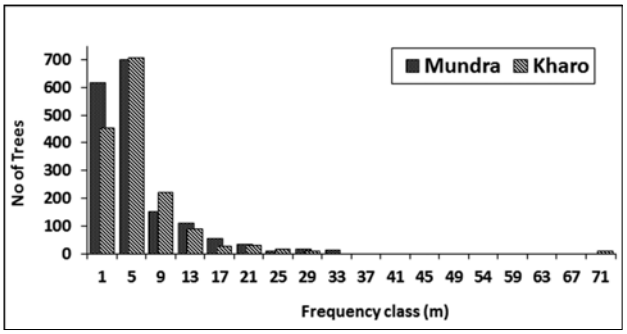

Figure.3 Canopy indices frequency classes of mature trees at Mundra and Kharo mangroves

classes followed by indices with ≤ 1 class contributing 28.8% of the total trees studied (Fig. 3). Canopy classes more than 21 CI constituted less than 1% of the total trees measured.

Regeneration class

Density of plants in the regeneration class (> 50 cm height) in all the four stations ranged between 62125/ha at Abban creek (AC) and 394062/ha at Navinal creek (NC) (Table 3). The highest density of 394062/ha recorded at Navinal mangroves indicates its high regeneration potential. This station with high regeneration density had lowest mature tree density (1820/ha). Contrary to normal trend, canopy index which is inversely related with regeneration potential was moderately high in this station with a mean CI of 4.69.

At Kharo station, density of plants in the regeneration class in all the six stations ranged between 6174 no/ha at Stn III and 41236 no/ha at Stn IV (Table 4). Stn II recorded the next lowest density of 7209 no/ha.

Recruitment class

Recruitment class plants (> 50 cm but < 1 m) in all the four study stations at mundra ranged between 26364/ha and 41521/ha (Table 3) at Navinal and Baradimatha creeks, respectively. Recruitment class was also fairly good at Abban and Bocha mangroves with a density of 39444 and 27888/ha. Highest recruitment density was recorded at Baradimatha and Abban mangroves where mature tree density was also highest (4325 and 3633/ha) indicating that this stands are dynamic.

At Kharo station, density of recruitment class plants in all the study stations ranged between 3868 no/ha and 18324 no/ha (Table 4) at II and V, respectively. Recruitment class was also fairly good at IV and VI mangroves with 11786 and 13675 no/ha. Highest recruitment density (18324 no/ha) recorded at Stn V also recorded fairly high mature tree (2701 no/ha) and regeneration density (34830 no/ha) indicating that this stand is young and yet to reach climax maturity.

Discussion

Kachchh mangroves distributed in the arid to semi-arid coastal belts are traditionally considered as the low dense mangroves which are mostly degraded (Blasco and Aizpuru, 1997). Structural attributes of Kachchh mangrove recorded presently are least comparable with other luxuriant mangrove formations of India like Sundarbans (Saha and Choudhury, 1995), Pitchavaram (Kathiresan *et al*., 1994) and Kakinada Bay (Satyanarayana *et al*., 2002) where higher densities of several orders have been recorded. The semi-arid coastal belt of Kachchh is known for its harsh environmental conditions like hyper-salinity (36-47 ppt), wider ambient temperature fluctuations (11.2 to 48.7°C), high evopo-transpiration (R/ETP- 0.03—0.20) and frequent natural disasters like cyclones and earthquakes. Added, the recent spurt in inland watershed development schemes deprive the meager seasonal run-off to neretic waters, rendering it singly conspecific formations of *Avicennia, marina*; a hardy species capable of tolerating

Table 3. Mature tree, recruitment and regeneration classes density and their ratio at Mundra mangroves

Stations	Mature Trees No/ha (1)	Recruitment Class-No/ha (2)	Regeneration Class No/ha (3)	Ratio 1 & 2	Ratio 1 & 3	Ratio 2 & 3
Abban (AC)	3633	39444	62125	1:11	1:17	1:2
Bocha (BC)	2526	27888	202308	1:11	1:80	1:7
Novinal (NC)	1820	26364	394062	1:14	1:216	1:15
Baradi (BMC)	4325	41521	140000	1:10	1:32	1:3
Average	3076		199624			

Table 4. Mature tree, recruitment and regeneration classes density and their ratio at Kharo mangroves

Stations	Mature Trees No./ha (1)	Recruitment Class-No/ha (2)	Regeneration Class No/ha (3)	Ratio 1&2	Ratio 1&3	Ratio 2&3
I	2995	5432	17658	1:1.8	1:5.9	1:3.3
II	1084	3868	7209	1:3.6	1:6.7	1:1.9
III	3559	4987	6174	1:1.4	1:1.7	1:1.2
IV	2926	11786	41236	1:4.0	1:14.1	1:3.5
V	2701	18324	34830	1:6.8	1:12.9	1:1.9
VI	2806	13675	20803	1:4.9	1:7.4	1:1.5
Average	2679	9679	21318	1:3.6	1:8	1:2.2

high physiological stresses (Macnae, 1986; Ye *et al*., 2005; Jayatissa *et al*., 2008). *Avicennia* represents the second dominant mangrove genus worldwide especially in harsh climatic areas (Duke, 2001). The Gulf of Kachchh with its poor and erratic rainfall to certain extent confirms Blasco's (1975) observation that Gujarat mangroves are floristically poor semi-arid formations. Though eight true mangrove species were reported earlier from the Gulf of Kachchh, *A. marina* was the only species recorded in the stations studied though sporadic occurrence of *Rhizophora mucronata* and *Ceriops tagal* were observed at Mundra mangroves. Kachchh mangroves are generally distributed on flat islands that are regularly inundated and fall under the fringe or over wash type of mangrove forests as per the physiographic classification of Lugo and Snedaker (1974). The overall stand density of 3076/ ha and 2679/ha recorded at Mundra and Kharo formations presently is comparable with the earlier reported mean density of 2100 no/ha (Thivakaran *et al*., 2003) at this mangroves. Given the ambience of high water and soil salinity and aridity prevailing in Kachchh coastal waters, mature mangrove tree density recorded in the two mangrove formations could be termed as moderate to good. The overall tree density in this study showed moderate variation among the stations studied. In both Mundra and Kharo mangroves, tree density was highest in low and mid tide level and in most of the cases the forest thinned down to scrubby formation with stunted trees due to less tidal flushing in high tide zone. Each stand studied was in different levels of development like mature forests (Navinal at Mundra and Stn VI at Kharo), development stage (Baradimatha at Mundra and Stn III & IV at Kharo) and regenerating stage.

Results obtained from the frequency distribution showed that different class frequencies of the three variables namely mature tree height, GBH and Canopy Index are dominant in one particular size ranges in both Mundra and Kharo mangroves. However, frequency classes of all the three variables showed skewness with discontinuous canopy class distribution and irregular height distribution. In Kharo mangroves, Stn III with a wider representation of all classes in all three variables seems healthy and more dynamic against stn I where frequency distribution of all classes is poorly represented. Similarly, in Mundra mangroves, Baradimatha and Navinal stands have better structural attributes in terms of height and wider distribution of different GBH and canopy classes. Water level and slope largely determine vegetation structure in any mangrove stand (Dahdouh-Guebas *et al*., 2001). Among Kharo mangroves, Stn III seems to have more conducive physical conditions that favor a healthy and dynamic stand unlike Stn I which seems to have reached its climax in succession. In addition, histogram obtained with the frequency distribution classes were bimodal or trimodal, indicating the possibility that the population investigated may be heterogeneous in nature obviously due to different micro-physiological condition of the habitat (Anderson, 1949).

Navinal mangroves (NC) at Mundra and Stn IV at Kharo recorded higher regeneration density. Factors like land elevation, tidal flushing, soil texture, seed dispersal/trapping and water current pattern would favor natural regeneration which could be the reason for this high regeneration potential in these stations. Similarly, these stations had highest regeneration : recruitment ratio (1:14 and 1:3.5) indicating poor entrance of regeneration class into recruitment category. In contrast, regeneration class at Baradimatha had the lowest ratio (1:3) with recruitment class which might be due to the highest mature tree density of 4325/ha at this stand. Similarly, regeneration and recruitment class ratio was highest at Navinal with its lowest mature tree density of 1820/ha favoring recruitment of saplings to higher classes. Abban mangroves with higher mature tree density of 3633/ha recorded the lowest entry of regeneration class into recruitment class which might be due to less gaps among the stand.

The highest regeneration class density of 41236 no/ha recorded at Stn IV in Kharo mangroves indicates its high regeneration potential. This station with high regeneration density had moderate mature tree density (2926 no/ha) with a highest mature tree and regeneration class ratio (1:14.1). Regeneration class at Stn III had lowest ratio (1:1.7) with mature trees which might be due to the high mature tree density of 3559 no/ha in this station. Similarly, regeneration and recruitment class ratio was highest at Stn IV (1: 3.5) which has fairly high mature tree density of 2926 no/ha. Entry of regeneration class into recruitment and mature tree category is influenced by other factors like propagule dispersal and predation.

Close positive relationship among younger classes and mature tree as observed by Dahdouh-Guebas *et al.* (2004) in Kenyan and Sri Lankan mangroves could be observed in the present study as well which is due to its inherent nature of spreading seeds widely. *Avicennia marina* spreads far and wider due to its pioneering nature and its dominance was ubiquitous in all the studied stations. In addition conducive canopy gaps, other physical factors like tide (by way of seed dispersal, influence on substratum) seem to play a role in determining the establishment of regeneration class and their successful entry into recruitment and mature tree category. Higher densities of younger classes recorded at Mundra and Kharo stations could be due to such conducive factors prevailing in these stands.

Based on the overall GBH recorded at Mundra mangroves, it could be concluded that the stands at Bocha and Navinal seem older than the other stands. On the contrary, mangroves at BMC which recorded high density and low GBH seems to be mature and youngest stand among all the stations studied. Likewise, mangrove stand of BC appears to be an older stand and seems to have reached its maximum density. Despite higher mature tree density, BMC and AC, recorded high recruitment class densities showing good potential for further growth. Generally, recruitment and generation classes are inversely related to mature tree density and canopy index besides other factors. However, in the present study this relationship did not appear clear. In BMC mangroves, highest density of recruitment and mature tree class was recorded and this was the youngest patch with favorable conditions for seed trapping and regeneration. Similarly, the ratio between mature tree density and recruitment was lowest among all the stands (1:10) indicating good entrance of recruitment classes into mature tree category. Contrary to this the recruitment and mature tree ratio was highest with lowest mature tree density indicating that this stand has reached its climax community stage.

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References

Anderson, E. 1949. Introgressive Hybridization. John Wiley & Sons Inc., New Delhi.

Blasco, F. 1975. The mangroves of India. *Trav. Sec. Sci. Tech*, 14:154-156.

Blasco, F. and M. Aizpuru. 1997. Classification and evolution of the Mangroves of India. *J. Trop. Ecol.* 38 (2): 357-374.

Chapman, V.J. 1976. *Mangrove vegetation.* J. Cramer, Vaduz, Liechtenstein, 477 pp.

Dahdouh-Guebas, F., I.V. Pottelbergh, J.G. Kairo, S. Cannicci and N. Koedam. 2004. Human-impacted mangroves in Gazi (Kenya): Predicting future vegetation based on retrospective remote sensing, social surveys and tree distribution. *Mar. Ecol. Prog. Ser.*, 272:77-92

Dahdouh-Guebas, F., T. Zetterstro, P. Ronnback, M. Troell, A.Wickramasinghe and N. Koedam. 2001. Recent Changes in Land-Use in the Pambala–Chilaw Lagoon Complex (Sri Lanka) investigated using Remote Sensing and GIS: Conservation of Mangroves vs. Development of Shrimp Farming. *Environ. Dev. Sustain.*, 4: 185–200.

De Silva, K.H. and S. Balasubramaniam. 1985. Some ecological aspects of the mangroves on the west coast of Srilanka. *Ceylon J. Sci.*, 18: 22-37.

Duke, N.C. 2001. Gap creation and regenerative processes driving diversity and structure of mangrove ecosystems. *Wetlands Ecol. Manage.*, 9:257–269.

Ellison, A.M. and E.J. Farnsworth. 1992. The ecology of Belizean mangrove root fouling communities: patterns of epibiont distribution and abundance and effects on growth. *Hydrobiologia.*, 247: 87-98.

Farnsworth, E.J and B.R. Jackes. 1987. A systematic revision of the mangrove genus *Sonneratia* (Sonneratiaceae) in Australasia, *Blumea.*, 32: 277-302.

FSI, 2009. India State of Forest Report. Forest Survey of India, Ministry of Environment & Forests, Govt. of India. Dehradun, India.

GEASMP (IMO/FAO/UNESCO/WMO/IAEA/UN/UNEP/ Joint group of experts on the scientific aspects of marine pollution, 1991. Reducing environmental impacts of coastal aquaculture. Reports and studies, GESAMP, No.47.

Hussein, M.Z. 1995. Silviculture of mangroves. *Unasylva.*, 46: 36-42.

ITTO, 1993. The economic and environmental value of mangrove forests and their present state of conservation. Prepared for the International Tropical Timber Organization. Japan International Association for Mangroves and International Society for Mangrove Ecosystems, Okinowa, Japan.

IUCN, 1996. Conservation management plan for ten selected mangrove sites in southwestern Srilanka. IUCN, Gland, Switzerland.

Jayatissa, L.P. W.A.A.D.L. Wickramasinghe, F. Dahdough-Guebas, M. Huxham. 2008. Interspecific Variations in Responses of Mangrove seedlings to two contrasting salinities. *Int. Rev. Hydrobiol.*, 93:700-710.

Kathiresan, K., M.X. Ramesh and V. Venkatesan. 1994. Forest structure and prawn seeds in Pichavaram mangroves. *Envir. Ecol.*, 12:465-468.

Kershaw, K.A., 1973. Sampling test of Comparison and application of quadrat measures. In: Quantitative and Dynamic Plant Ecology. 2nd edn. William Clowes and Sons Limited, London.

Lewis, R.R, 1990. Creation and restoration of coastal wetlands in Puerto Rico and the US Virgin Islands. In : J.A. Kusler, M.E. Kentula (Eds.), In: *Wetland creation and restoration : The status of science*, Vol. I, Regional reviews, Island Press, Washington DC, p. 103-123.

Linden, O. and A. Jernelov. 1980. The mangrove swamp – an ecosystem in danger, *Ambio.*, 9: 81-88.

Lugo, A. E. and S.C. Snedaker. 1974. The Ecology of Mangroves. *Annu. Rev. Ecol. Syst.*, 5: 177 – 185.

MacNae, W. 1986. A general account of the fauna and flora of mangrove swamps and forest in the Indo-west-Pacific region. *Adv. Mar. Biol.*, 6:73-270.

Marshall, N. 1994. Mangrove conservation in relation to over all environmental considerations. *Hydrobiologia.*, 285: 303-309.

McGill, J.T. 1959. Coastal classification maps. In: R.J. Russell (ed.), *Proceedings of the Second coastal geomorphology conference.* Coastal studies Institute, Lousiana State University, Baton Rouge, p. 1-22.

Mueller-Dombois, D., Ellenberg, H., 1974. Aims and Method of vegetation Ecology. John Wiley & Sons, New York.

Pernetta, J.C. 1993. Marine protected areas in the South Asian Seas region – Srilanka. A marine conservation report. IUCN, Gland, Switzerland, 67 pp.

Saenger, P., E.J. Hegerl and J.D.S. Davie. 1983. Global Status of Mangrove Ecosystems. *The Environmentalist.*, 3: 1-88.

Saha, S. and A. Choudhury. 1995. Vegetation analysis of restored and natural mangrove forest in Sagar island, Sundarbans, east coast of India. *Indian J. Mar. Sci.*, 24:133-136.

Satyanarayana, B., A.V. Raman, F. Dehairs, C. Kalavati and P. Chandramohan. 2002. Mangrove floristic and zonation patterns of Coringa, Kakinada Bay, East Coast of India, *Wetlands Ecol. Manage.*, 10: 25–39.

Semesi, A.K. 1998. Mangrove management and utilization in eastern Africa, *Ambio.*, 27: 620-626.

Spalding, M., F. Blasco and C. Field. 1997. World Mangrove Atlas. The International Society for Mangroves Ecosystems, Okinawa, 178 pp.

Terchunian, A., V. Klemas, A. Alvarez, B. Vasconez and L. Guerrero. 1986. Mangrove mapping in Eucador: The impact of shrimp pond construction. *Environmental management.*, 10: 345-350.

Thivakaran, G.A. 2011. Coastal Ecology of Kachchh- Status, Issues and Problems. In: K. Kajju, G.A.Thivakaran, P. Patel (Eds.), State of Environment of Kachchh. GEER Foundation and Gujarat Institute of Desert Ecology, p. 67-87.

Thivakaran, G.A., A. Saravanakumar, J. S.Serebiah, W. Sunderraj and V. Vijaykumar. 2003. Vegetation Structure of Kachchh Mangroves, Gujarat, Northwest Coast of India., *Indian. J. Mar. Sci.*, 32(1): 37-44.

Tomlinson, P.B. 1986. The Botany of mangroves. Cambridge University press, Cambridge, 195 pp.

Upadhyay, V.P, R. Rajan. and J.S. Singh. 2002. Human – mangrove conflicts: The way out. *Curr. Sci.*, 83(11): 1328-1336.

Walsh, G.E. 1974. Mangroves: a review. In: R.J. Reimold, W.H. Queen (Eds.), Ecology of Halophytes, Academic press, New York, 174 pp.

Wolanski, E. 1992. Hydrodynamics of tropical coastal marine systems. CRC Press, Boca Ratton, Florida, USA., 2-27 pp.

World Conservation Monitoring Center (WCMC), 1994. Biodiversity data source book. World conservation press, Cambridge, UK, In: M. Collins, J. Sayer and T. Whitmore (Eds.), The conservation Atlas of tropical forest: Asia and the Pacific, McMillan Press, London, 187, 212 pp.

Ye Y. N.F.Y. Tam., C.Y. Lu. And S.H. Wong. 2005. Effects of salinity on germination, seedling growth and physiology of three salt secreting mangrove species. *Aquat. Bot.*, 83:193–205.