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Stand structure and environmental factors of mangroves of Abdasa, Gujarat, India

R. Madhavan Unny*, K. Karthika and S. Paulsamy
Kongunadu Arts and Science College, Coimbatore-641 029, Tamil Nadu, India.

*Correspondence e-mail: sumamadhavan2004@gmail.com

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Original Article

Abstract

Mangrove forest structure in terms of adult, recruitment and regeneration categories along with seven governing physico-chemical parameters was investigated in the Abdasa Taluka of Kachchh District, Gujarat. Mangrove vegetation in the categories of mature trees (≥1 m), regeneration class (<60 cm) and recruitment class (>60 cm and <1m) were analyzed in six stations. To delineate the forest structure, 2210 trees in 74 quadrats of 10×10 m in 28 transects were investigated using the line intercept transect method. For mature tree density, a range of 1963/ha and 3800/ha was estimated while the density of younger classes such as regeneration and recruitment categories ranged widely. Tree height and diameter at breast height (DBH) in all the six stations ranged from 1 to 6.7 and 0.3 to 38.8 cm, respectively. Tree height in 42.8% of trees was in the size range of 1.8 to 2.5 m while 80.8% of trees were in the DBH class of 0.3-8.3 cm. The density of the regeneration class in all the six stations exceeded that of the recruitment class, indicating good regeneration potential of the stand. The entrance of younger classes into the mature tree category varied significantly among the stations investigated. In the light of ongoing developmental initiatives, the conservation significance of Abdasa mangroves is highlighted to draw the researchers' and managers' attention.

Keywords: *Stand structure, mature trees, younger classes, environmental parameters, Avicennia marina*

Introduction

Indian mangroves constitute 3.3% of the global distribution with an extent of 4975.2 km^2 and with 46 true mangrove species (Ragavan *et al.*, 2016; FSI, 2021). However, most of the formations are with a single species, *Avicennia marina* Vierth. var. *acutissima* Stapf and Mold, known for its extreme tolerance to ambient salinity, temperature and other environmental thresholds (Morrisey *et al.*, 2010). Extending to an area of 1175 km^2 (FSI, 2021) mangroves of Gujarat state in western India are located in an arid to the semi-arid coastal environment and are generally considered scrubby and open in nature (FSI, 2021). Mangrove formations of Kachchh District are the largest contiguous stand on the Indian west coast while other patches further south have almost become vestigial. With an extent of 798.74 km^2, Kachchh mangroves constitute 67.5% of Gujarat and 16% of Indian mangroves (FSI, 2021). These mangroves are floristically poor with the predominance of *A. marina* though very few individuals of *Rhizophora mucronata, Ceriops tagal* and *Aegiceros corniculatum* were reported in Mundra and Kandla coasts of Kachchh District (DasGupta and Shaw, 2013; Thivakaran *et al.*, 2018). Contrarily, the southern bank of the Gulf of Kachchh (GoK), constituting Marine National Park and Sanctuary, has five true mangrove species (Singh, 2000; GEC, 2012).

With the largest number of ports and harbours handling around 60% of the country's crude oil requirements and heavily clustered coastal industries, GoK and its marine ecosystems, of late, are witnessing human-induced degradation despite the declaration of Marine National Park (MNP). Increasing coastal industrial activities have impacted many physical and chemical ecosystem characteristics as is evidenced in many mangrove formations. Against this backdrop, understanding different facets of GoK mangroves, including its vegetation structure is imperative. Earlier scientific studies on GoK mangroves mostly dealt with associated biota, floral diversity, conservation, remote sensing and vegetation structure (Singh, 2000; Nayak and Anjali, 2001; Nair, 2002; Thivakaran *et al.*, 2003, Saravanakumar *et al.*, 2009; Patel *et al.*, 2010). Recently, Thivakaran *et al.* (2018) carried out an extensive analysis of mangrove vegetation structure for the whole of GoK mangroves. Mangrove distribution and cover through remote sensing were earlier carried out in Gujarat by Srivastava *et al.* (2015) and Khare and Shah (2019). However, remote sensing studies, though highly significant, do not yield taxonomic, ecological and physiological data since actual fieldwork on the ground is essential to understanding the ground reality of mangroves (Ball and Pidsley, 1988). For sustained conservation and management, knowledge of the structural attributes of this tidal forest needs to be periodically updated.

Studying forestry variables and parameters and understanding its vegetation dynamics can generate valuable information on the past, present and even future vegetation structure of the stand and yields information on its productivity (Dahdouh-Guebas *et al.*, 2002). In addition, robust conservation and management efforts of mangroves require reliable information on their various scientific features such as their vegetation structure, associated faunal components and vital physical and chemical characteristics (Liu *et al.*, 2014; Sitoe *et al.*, 2014). The recent surge in coastal industrial development along with immense upstream water conservation measures to tide over the aridity of this region is another compelling reason warranting increased understanding of this delicate ecosystem.

In this paper, we have provided quantitative data on the vegetation structure of the mangroves of Abdasa Taluka in the Kachchh District of Gujarat. Mangrove formation of this coast needs increased scientific attention given the developmental and human threats it faces and its conservation significance. Of late, this tidal forest faces human impact from the upcoming coastal industries, ports and jetties underlining the need for scientific studies and increased conservation efforts of these mangroves. This prompted us to undertake the study which investigates the forest structure and governing crucial physico-chemical parameters.

Material and methods

Kachchh District, Gujarat, is India's largest district, and Abdasa Taluka is located in its northwest (Fig. 1). This taluka has several geographical, demographical, political and ecological peculiarities. The irregular and undulating coastline of this taluka is 108 km long, with many creek systems harbouring mangroves and represents 22.7% of the 475 km coast of the Kachchh District. Sir creek along the north-western periphery of the taluka serves as the (disputed) international border with Pakistan. The district receives a very poor mean annual rainfall of 390 mm (1988 to 2017) and has a humid environment with an extreme temperature fluctuation of 0 to 47° C rendering this coastal taluka highly arid. As a result of the lack of perennial rivers, poor rainfall, and low agricultural productivity, human density is very low at 48.86 persons per square kilometre (2011 Census). The benefit of even this meagre rainfall is denied to coastal mangroves as numerous check dam projects do not allow any freshwater run-off to the coastal region, elevating the already hypersaline coastal waters to much higher salinity levels. Poor freshwater input due to poor rainfall renders the coastal mangroves florally poor in diversity with only one true mangrove species, *A. marina* known for its environmental perseverance to harsh conditions. The remoteness of the taluka, presence of defence forces and less population density rendered Abdasa mangroves undisturbed. In recent years, however, many calcium mining, cement and thermal industries with their jetties have come up amidst mangrove formation. Tides are semi-diurnal in nature with tidal amplitude ranging from 4-6 m. Waves are not much pronounced resulting in a tranquil and calm coast enabling the formation and proliferation of a mangrove ecosystem.

The line intercept transect method (Thivakaran *et al.*, 2018) was employed to study the mangrove architecture in the chosen six stations from November 2019 to March 2020. The study stations were chosen in such a way that they represented the general features of Abdasa Mangroves. Micro-level study locations in each of the six stations were chosen based on an initial reconnaissance survey and consultation of Survey

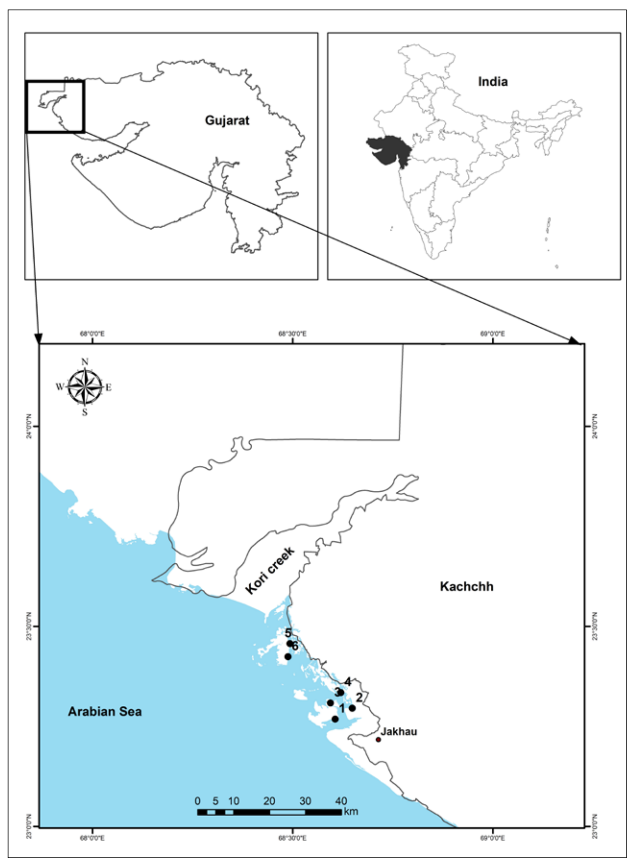

Fig. 1. Map showing the study area and sampling locations

of India toposheets along with the forest officials stationed at the taluka headquarters at Naliya. In total, 74 numbers of 10×10 m quadrates in 28 transects covering 2210 trees in six different stands in a coastal stretch of ~100 km were studied for their different vegetation attributes. Along with the mangrove vegetation traits, seven crucial governing environmental parameters were also studied. Studies were carried out during low tide when all the stands were well exposed. For each transect and quadrate studied, GPS position was noted down for future reference.

Three quadrates of 10×10 m size were laid randomly in each transect horizontally from the waterfront to the landward forest edge. In each station around 3-6 transects were laid to cover the stand more accurately. The transect length and the distance between quadrates differed in each transect in tune with the forest width from low to high tide levels. Tree morphometrics such as height, Diameter at Breast Height (DBH) and canopy length and width were measured along with the number of trees in each quadrate. The canopy was assessed in terms of canopy index (CI) obtained by multiplying canopy length and width. DBH was calculated by dividing the Girth at Breast Height (GBH) of all mature trees by a value of 3.14 (*pi value*). Sub-quadrates of 1 × 1 m and 2 × 2 m were laid within larger quadrates for younger class density estimation as suggested by Thivakaran *et al.* (2018). Germinating seedlings less than 50 cm tall were considered a regeneration class whereas recruitment classes were in the height range of 50 to 99 cm. Density values for mature trees, regeneration and recruitment classes were expressed as numbers per hectare (No/ha). To understand the size class distribution of mature trees, two parameters, tree height and DBH were statistically subjected to a frequency of occurrence analysis and the results are graphically represented.

Samples for physico-chemical parameters of creek water and mangrove soil governing mangrove ecology were collected during the low tide when the mangrove stands were well exposed. Creek water and pore water salinity, expressed in terms of practical salinity unit (psu) were measured in triplicate using a calibrated refractometer (ORAPXI). Similarly, for pore water pH and soil texture, triplicate samples were collected at three tidal levels from the low to high tide mark. For estimating pore water and creek water pH in the site, a standardized pH pen (Hanna make) was used. Three major fractions of the mangrove soil namely, sand (0.075-4.75 mm), silt (0.002-0.075 mm) and clay (< 0.002 mm) were segregated from the triplicate samples of three tidal levels using a mechanical shaker and the average was considered. For estimating the total suspended solids (TSS-mg/l), surface water temperature (ºC) and water turbidity (NTU), the methods suggested by APHA (2017) were followed.

Results

Mature tree density

The density of mature trees in the six stations ranged between a minimum of 1963/ha at station I and a maximum of 3800/ha at station VI with an overall mean density of 3070/ha (Table 1). Density at Station III was equally good with a value of 3754/ha. Stations II, III and IV had mature tree densities of higher order exceeding 3000/ha. Only at stations I and V, recorded density values were lower than the overall mean of 3070/ha.

Tree height

The minimum height of a mature tree was taken as 1 m, while the maximum height of trees at different sites ranged between 3.1 and 6.7 m, with a mean value of 2.02 (±0.737) m. At stations, I and II, average values of height were minimum (1.57 m) and maximum (2.25 m), respectively among the six stations (Table 1). Only at stations I and VI, the mean tree height was lower than the overall mean of 2.02 m. Using pooled tree heights of all the stations, frequency class analysis at 0.7 m intervals revealed that 42.8% of the trees were in the 1.8-2.5 m class, followed by 35.8% in the 2.6-3.3 m class (Fig. 2). Following this, trees in 3.4-4.1 m and 4.2-4.9 m classes constituted 12.4 and 3.9%

Table 1. Vegetation structure of Abdasa Mangroves, Gujarat

Stations	Density (No/ha)	Tree height (m)			DBH (cm)			Canopy Index		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
I	1963	1	3.1	1.57 (±0.027)	0.955	7.96	4.41 (±0.08)	1	64	7.7 (± 4.67)
II	3433	1	6.7	2.25(±0.878)	0.955	35.66	7.17 (±0.273)	1.2	32	8.5 (± 2.55)
III	3755	1	5	2.13 (±0.688)	0.318	29.617	4.48 (±2.93)	4	61	6.65 (± 4.67)
IV	3362	1	5	1.96 (±0.716)	0.637	30.255	6.24 (±3.738)	1.5	15.5	8.7 (± 3.22)
V	2108	1	4.5	2.145 (±0.743)	1.27	38.853	6.491 (±4.225)	1.5	4.5	2.25 (± 0.94)
VI	3800	1	4.2	2.02 (±0.640)	1.27	25.477	6.560 (±3.704)	1	63	5.62 (± 5.22)
Average	3070	1	4.75	2.01 (±0.615)	0.90	27.97	5.89 (±3.96)	1.70	40.00	6.57 (±3.54)

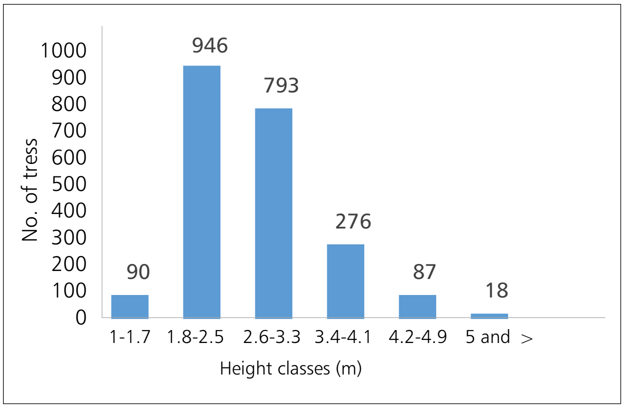

Fig. 2. Height frequency classes (m) in Abdasa Mangroves

of the total trees analyzed. Only 18 tallest trees taller than 5 m were recorded mostly at station II, accounting for a meagre 0.18% of the total trees (2210). The predominant height class of 1.8-2.5 m was recorded in almost all the six stations proving that the majority of Abdasa Mangroves are coming under this group. The number of trees in the frequency height class 1-1.7 m was also very low (90) accounting for 4% of the total trees analyzed.

Diameter at breast height (DBH)

The DBH of the 2210 trees studied ranged from 0.318 to 38.85 cm at stations III and V, respectively with an overall average value of 5.89 cm (Table 1). Variations of DBH at all the stands were wider except at station I, where DBH range was lesser. Station II recorded the highest mean DBH of 7.17 cm whereas it was lowest at station I with a value of 4.41 cm.

Segregation of DBH into different frequency classes of 4 cm interval revealed a dominance of 0.3-4.2 and 4.3-8.3 cm classes, contributing 39.4 and 41.4%, respectively (Fig. 3). Other DBH frequency classes were less than 10% of the total trees except

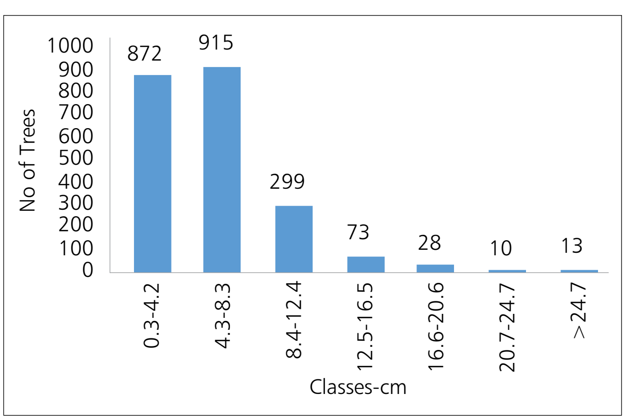

Fig. 3. DBH frequency classes (cm) in the Abdasa Mangroves

for 8.4-12.4 cm class which accounted for 13.5% of the total trees. Trees with DBH of ≥20 cm were very less in number, constituting only 1% of the total studied trees and occurring at stations II, IV and V.

Canopy index

The dimension of the mature tree crown was expressed in terms of the canopy index calculated by multiplying its length and breadth. The overall range of canopy index was between a minimum of 1 to a maximum of 64 with an overall average value of 6.57 (Table 1). The mean canopy index was highest at station IV with a value of 8.7, and it was lowest (2.25) at station V. Stations II, III and IV recorded higher than the mean values of canopy indices. The segregation of canopy indices into five major frequency classes at an interval of 5 indicated that among the different canopy index classes, the 5-6 class was most dominant with 84.2% of the total trees (Fig. 4). Rest of all four canopy index classes were less than 10% of the total trees measured. The largest canopy index of > 25 accounted for only 1.3% of the total trees.

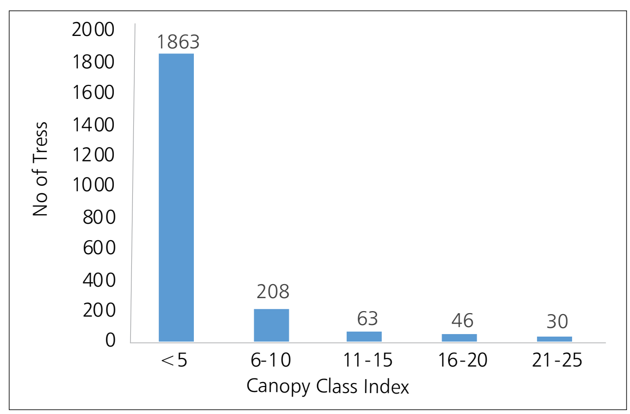

Fig. 4. Canopy index frequency classes in the Abdasa Mangroves

Regeneration class

The average density of regeneration class in all the six stations was 153642/ha with a range of 39444 and 478666/ha at stations VI and I, respectively (Table 2). Stations V and VI exhibited a higher rate of transition of regeneration saplings into recruitment class (1:4 and 1:5) proving fairly better forest health, succession and dynamics in these stations. Contrarily, the transition ratio of these younger classes was poor at stations I (1:49) and IV (1:26).

Recruitment class

With a range of 7500 and 13917/ha in all six stations, the density of the recruitment class was lower than the

Table 2. The ratio between different age classes and mature trees in Abdasa Mangroves

Stations	Density-No/ha			Ratio 1:2	Ratio 2:3
	Mature tree	Recruitment class	Regeneration class		
I	1963	9756	478666	1:5	1:49
II	3433	8846	61250	1:2.5	1:7
III	3755	7579	42051	1:2	1:6
IV	3362	9306	240000	1:3	1:26
V	2108	13917	60440	1:7	1:4
VI	3800	7500	39444	1:2	1:5
Average	3070	9484	153642	1:3.1	1:16

regeneration class but higher than the mature tree category (Table 2). It was especially high at stations IV (13917/ha) and I (9756/ha), while it was poor at stations VI (7500/ha) and III (7579/ha). Stations VI with the lowest recruitment class density of 7500/ha had the highest mature tree density of 3800/ha.

Abiotic factors

Creek water and pore water salinity is the foremost factor that determines mangrove floral diversity, stand structure and associated biota (Branoff and Martinuzzi, 2020). The average creek water salinity in the six study stations was 41.5 psu which was much higher than the normal seawater salinity of 35 psu (Table 3). Though hypersaline, the variation in creek water salinity was not substantial in different stations and ranged from 40.2 to 43 psu. Pore water salinity values were much higher than that of creek water with an average value of 48.7 psu with a range of 44.4 and 53.3 psu (Table 3). Creek water pH was alkaline and fluctuated between 7.3 and 8 at stations I and III with a mean of 7.65. Contrary to creek water, pore water pH was acidic and ranged from 6.5 to 7 in all tidal levels with an average value of 6.7. Surface water temperature in the mangrove-lined creeks ranged from 24.6 to 29.2ºC with an average of 26.6ºC (Table 3). Turbidity averaged 148 NTU with a low value at station III (59 NTU) and a high value at station II (188 NTU). A similar pattern of variation in suspended solids was observed in the creek water and ranged from 145 mg/l to 210 mg/l. Mangrove sediments predominantly consisted of silt and finer clay fractions whereas sand and coarser clay fractions in the total composition were the least (Table 4). Different fractions in the mangrove sediments followed the order of silt>finer clay> coarser clay> sand which is common in any mangrove environment. This could be observed in the sediments of all six stations. At station I, the sand fraction was least (9.28%) indicating poor winnowing and wave action in the mangrove proper. Similarly, the finer clay fraction was highest at station I. No significant variation among silt and clay content could be discerned in all the study stations.

Table 3. Mean Values of selected environmental parameters in the study sites of Abdasa Mangroves

Stations	Creek Water					Pore water							
						Salinity (ppt)				pH			
	Salinity (ppt)	pH	NTU	TSS (mg/l)	Temp-C	LTL	MTL	HTL	Avg	LTL	MTL	HTL	Avg
I	41	7.3	169	156	29.2	45.7	48.2	51	48.3	6.6	6.6	6.4	6.5
II	40.2	7.9	188	210	27.7	41.8	43.6	47.9	44.4	6.9	7.2	6.8	7.0
III	42	8	59	176	24.6	43	46.2	46	45.1	6.6	6.9	6.9	6.8
IV	41.5	7.4	138	187	26.5	43.8	51.7	55.8	50.4	6.7	6.7	6.8	6.7
V	41.8	7.4	146	154	25.5	43.8	52.2	56	50.7	6.7	7	6.8	6.8
VI	43	7.9	188	145	26.2	42	57	61	53.3	6.8	6.9	6.9	6.9

HTL- High Tide Line; MTL-Mid Tide Line; LTL-Low Tide Line; ppt- Parts per Thousand

Table 4. Sediment grain size in the study stations of Abdasa Mangrove

Stations	Silt (%)	Clay (%)		Sand (%)
		Fine	Course	
I	26.25	38.31	26.2	9.28
II	22.34	30.25	29.76	17.66
III	31.21	35.43	19.21	14.23
IV	15.6	25.12	27.88	31.4
V	21.21	27.1	28.44	23.32

Per cent values are average of 3 samples

Threats and conservation issues

Gujarat ranks first in industrial development among Indian states with an overall GDP of ~12% which is well above the average national GDP of 7-6%. State and Central Government's initiatives to promote industries resulted in large-scale, coast-centric development such as ports, jetties and harbours (Table 5). Capital and maintenance dredging by these ports, regular vessel movement, oil spillage and near coastal construction activities discharge an enormous quantity

Table 5. Major coastal industries close to mangrove ecosystem of Abdasa

Industry Type	Number	Remarks
Cement	3	Jetties amidst thick mangrove formation; regular vessel movement, dredging and material handling
Fishing Harbor	1	Located opposite to a mangrove stand across the creek; vessels berthing, movement, organic and oil waste discharge
Ports	5	In close proximity of thick mangrove formation; oil spillage, vessel movement, material handling, dredging and draft maintenance
Steel	1	4 km inland with their jetty near a mangrove stand
Salt	3	3-4 km from mangrove formation, discharge of brine and elevated salinity, mangrove habitat fragmentation, obstruction of freshwater input
Mining	4	Inland, obstructs freshwater inflow to mangroves through habitat fragmentation, increased sedimentation
Thermal power	1	Close to mangrove formation; habitat fragmentation and obstruction of freshwater input

Table 6. Threat perception and their status for Abdasa Mangroves.

S. No	Threats	Range and Scale
1	Natural Disasters	Low to High –Increasing
2	Population Pressure	Low-Stable
3	Traditional Over exploitation	High-Increasing
4	Forestry	High- Stable
5	Agriculture	Medium-Increasing
6	Aquaculture	Low-Stable
7	Salt Production	High-Increasing
8	Mining	High-Increasing
9	Urban and Industrial Development	Very High-Increasing
10	Tourism	Low-Stable
11	Hydrological Diversions-Dams	Very High-Increasing
12	Coastal Pollution	High-Increasing
13	Management Short comings	Medium-Decreasing

of sediments in the mangrove proper enhancing the sedimentation rate and impacting mangrove physiology and health. All the ports/jetties are regularly expanding their material handling capacity with an entailing impact on the mangroves. In addition, grazing and fodder collection was earlier reported to remove huge mangrove resources to the tune of 709 tons/ha (Thivakaran, 2017). Analysis of the extent of threat perception in terms of 13 major threats indicated that seven threats are under the 'very high' and 'high' categories (Table 6). Large-scale plantation to conserve and promote the existing stand is vigorously followed by many government departments. Plantation to the tune of 25000 ha was carried out so far in the different coastal belts of Kachchh District. This, along with other natural factors, has led to a sustained expansion of mangrove cover in the district from 757 to 798.74 km^2 between 2005 and 2021 (FSI, 2021). For this phenomenon to be sustainable, mangrove restoration and rehabilitation through other bio-physical means such as widening and removing the blocks in natural mangrove feeder canals were earlier suggested (Thivakaran, 2017). Participation of stakeholder coastal communities as a way to ward-off poor post-plantation survival has become a norm now in all plantation activities. Furthermore, the promulgation of the Coastal Regulation Zone (CRZ) notification (2019) and its strict enforcement on coastal development have prevented mangrove reclamation in recent years. Livestock grazing, developmental initiatives and urbanization which entail resource degradation constitute a major threat to mangroves in India and elsewhere (GEC, 2012; Zamprogno, 2016). Similar to other mangrove formations, grazing and fodder collection is a major threat to the mangroves of Abdasa Taluka. An important use of mangroves to the coastal population in Kachchh is fodder. As per the census of 2002, the seven coastal talukas of Kachchh have a cattle and camel population of 9, 34,668 numbers. About 90% of households own livestock in Kachchh coastal villages (Hirway and Goswamy, 2007).

Discussion

Mangrove vegetation structure studies at different layers have helped not only to understand the present status but to predict future dynamics of the forests (Dahdouh-Guebas *et al*., 2002). It also helps the managers to determine appropriate remedial measures to negate developmental impacts. Moderate forest structure in terms of height and density recorded in this study is attributable to the governing environmental parameters such as low rainfall, poor terrestrial run-off and high creek water and pore water salinity. Forest structure as a function of rainfall, soil and pore water salinity, and tidal flooding is evident from many earlier studies (Zamprogno *et al*., 1916; Branoff and Martinuzzi, 2020; Bathmann *et al*., 2021). Especially, the role of creek water and pore water salinity is known to characterize the mangrove forest structure (Calegario *et al*., 2015). But tidal flooding did not appear to play a role in the present study area, confirming the findings of Branoff and Martinuzzi (2020). The whole mangrove forest of Abdasa Taluka is solely composed of a single species, *A. marina* whose physiological tolerance to many adverse conditions is well proved (Ye *et al*., 2005; Jayatissa *et al*., 2008; Cheng *et al*., 2020). A close structural similarity of Abdasa Mangroves with the mangroves of Karachi of Pakistan could be gleaned from the studies of Khan and Aziz (2001) wherein *A. marina* was also shown to be the tallest among the three species in higher salinities attesting to the present results. Globally, mangrove tree density showed a very wide variation ranging from 11 trees/ha to 33570 trees/ha (Rani *et al.*, 2016). Thivakaran *et al.* (2018) reported an average tree density of 3070/ha after studying the entire Gulf of Kachchh mangroves in an earlier study. However, tree density values reported in the present study are much lower than many of the Indian mangrove formations (Joshi and Ghose, 2003; Upadhyay and Mishra, 2014; Rani *et al.*, 2016; Singh, 2020).

Tree density in any mangrove formation depends directly on the density of younger classes such as regeneration and recruitment categories. The establishment and survival of younger classes is a function of seed availability which in turn is determined by many biophysical and biochemical factors such as tidal currents, water and pore water salinity and rainfall which act to limit many other forest variables (Ruiz-Fernández *et al.*, 2018). Increased density in the order of mature trees<recruitment class<regeneration class observed in the present study was earlier reported in the mangroves of India, Kenya and Sri Lanka (Thivakaran *et al.*, 2003; Dahdouh-Guebas, 2004). Higher densities of plants near the low water mark and reduced densities towards the landward side observed presently is a common phenomena in all mangrove formations worldwide as a function of differential tidal reach. Similarly, the floral biodiversity in the mangrove ecosystem is directly linked to freshwater input by way of rainfall and terrestrial runoff (Naskar and Mandal, 1999; Ragavan *et al.*, 2016). In the frequency analysis of mature tree height, all six height classes were represented in different proportions. Similarly, their DBH frequency was also well represented with the majority of the trees confined to initial lower classes, indicating the dynamic and rejuvenating nature of the stand. Using height and DBH class frequencies, Dahdouh-Guebas *et al.* (2004) and Rani *et al.* (2016) established the stand dynamics and succession process of Kenyan, Sri Lankan and Indian mangroves. Inferring the present results in light of their findings indicate that the Abdasa stand is young and highly dynamic in nature.

Abiotic factors (salinity, temperature, pH, TSS and NTU) among the stations did not vary much showing a uniform environmental *milieu* in all the studied stations. However, pore water salinities varied among and within stations which is apparently due to differing tidal inundation which influences forest structure to a great extent (Bathmann *et al.*, 2021). The pattern of increasing pore water salinity perpendicular to the waterfront observed in the study locations was a function of tidal flooding, which in turn, influences the tree height, DBH and other structural characters negatively (Rani *et al.*, 2016; Domínguez *et al.*, 2016; Ruiz-Fernández, 2018). In the sediment composition, recorded differences among different sediment fractions are obviously due to different degrees of wave-induced winnowing activity. Less wave action in all the study stations seems to ensure less turbulence and a tranquil environment for the establishment and survival of mangrove seedlings. As an exception, the highest proportion of sand (31.4 and 31.23%) recorded at stations IV and VI could be due to increased wave action and the open nature of the coast in these areas. The ongoing industrial development along the Abdasa coast is of great concern as mangrove maturity and succession are heavily hampered by anthropogenic activities (Zamprogno, 2016). The future well-being of these mangroves which is the largest entity on India's west coast will depend on the proactive management approaches going to be adopted in this region.

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References

APHA. 2017. Standard Method for the Examination of Water and Wastewater. 23th Edition. American Public Health Association. 1504 pp.

Ball, M. C. and S. M. Pidsley. 1988. Establishment of tropical mangrove seedlings in relation to salinity. In: H. Larson, R. Hanley and M. Michie (Eds.) Proceedings of a Workshop on Research and Management in Darwin Harbour, Darwin, p. 123-134.

Bathmann, J., R. Peters, R. Reef, U. Berger, M. Walther and C. E. Lovelock. 2021. Modelling mangrove forest structure and species composition over tidal inundation gradients: The feedback between plant water use and porewater salinity in an arid mangrove ecosystem. *Agric. For. Meteorol.*, 308-309.

Branoff, B. and S. Martinuzzi. 2020. The Structure and composition of Puerto Rico's urban mangroves. In: Special issue of Forest Stand Management and Biomass Growth" forests, 11(10): 1119.

Calegario, G., M. S. M. B. Salomão, C. E. de Rezende and E. Bernini. 2015. Mangrove forest structure in the São João River estuary, Rio de Janeiro, Brazil. *J. Coastal. Res.*, 31 (3): 653–660.

Cheng, H., A. Inyang, C. D. Li, J. Fei, Y. W. Zhou and Y. S. Wang. 2020. Salt tolerance and exclusion in the mangrove plant *Avicennia marina* in relation to root apoplastic barriers. *Ecotoxicology*, 29: 676–683.

CRZ. 2019. Coastal Regulation Zone Notification. 2019. Ministry of Environment, Forest and Climate Change, Government of India, Gazette of India dated 18th January 2019. Part-II, Sec. 3(i): 30-56.

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., J. G. Kairo, L. P. Jayatissa, S. Cannicci and N. Koedam. 2002. An ordination study to view vegetation structure dynamics in disturbed and undisturbed mangrove forests in Kenya and Sri Lanka. *Plant. Ecol.*, 161:123–135.

DasGupta, R. and R. Shaw. 2013. Changing perspectives of mangrove management in India –An analytical overview. *Ocean. Coast. Manag.*, 80: 107-118.

Dominguez-Cadena, R., R. Riosmena-Rodriguez and J. L. L. José. 2016. Forest structure and species composition of mangroves in the eastern Baja California Peninsula: The role of microtopography. *Wetlands*, 36(3): 515-523.

FSI. 2021. India State of Forest Report. Forest Survey of India, Ministry of Environment & Forests, Govt. of India. Dehradun, India.

GEC. 2012. Mangrove restoration through public-private partnership-Gujarat. Gujarat Ecology Commission, Udyog Bhavan, Gandhinagar, India, 86 pp.

Hirway, I. and S. Goswami. 2007. Valuation of mangroves in Gujarat; Gujarat Ecology Commission, Gandhinagar, 96 pp.

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

Joshi, H. and M. Ghose, 2003. Forest structure and species distribution along soil salinity and pH gradient in mangrove swamps of the Sundarbans. *Trop. Ecol.*, 44(2): 197–206.

Khan, M. A. and I. Aziz. 2001. Salinity tolerance in some mangrove species from Pakistan. *Wetl. Ecol. Manag.*, 9: 219-223.

Khare, S. S. and D. G. Shah. 2019. Mangrove vegetation change in Vagra Taluka, Bharuch District, Gujarat, India from 1978 to 2012. *Indian J. Mar. Sci.*, 48(04): 504-510.

Liu H, H. Ren, D. Hui, W. Wang, B. Lion and Q. Cao. 2014. Carbon stocks and potential carbon storage in the mangrove forests of China. *J. Environ. Manage.*, 133: 86-93.

Morrisey, D. J., A. Swales, S. Dittmann, M. A. Morrison, C. E. Lovelock and C. M. Beard. 2010. The ecology and management of temperate mangroves. In: R. N. Gibson, R.J.A. Atkinson and J. D. M. Gordon (Eds.) Oceanography and marine biology: An Annual Review. CRC Press, p. 43-160.

Nair, V. R. 2002. Status of flora and fauna of Gulf of Kachchh. National Institute of Oceanography, India, 157 pp.

Naskar, K. R. and R. N. Mandal. 1999. Ecology and biodiversity of Indian mangroves. Daya Publishing House, New Delhi, India, 783 pp.

Nayak S. and B. Anjali. 2001. Application of remote sensing data to monitor mangroves and other coastal vegetation of India. *Indian J. Mar. Sci.*, 30: 195-213.

Patel, N. T., A. Gupta and A. N. Pandey. 2010. Salinity tolerance of *Avicennia marina* Forssk. Vierh. From Gujarat coast of India. *Aquat. Bot.*, 93: 9-16.

Ragavan, P., A. Saxena, R. S. C. Jayaraj, P. M. Mohan, K. Ravichandran, S. Saravanan and A. A. Vijayaraghavan. 2016. Review of the mangrove floristics of India. Taiwania, 61(3): 224-242.

Rani, V., S. Sreelekshmi, C. V. Asha and S. B. Nandan. 2016. Forest structure and community composition of Cochin mangroves, south-west coast of India. *Proc. Natl. Acad. Sci., India, Sect. B, Biol. Sci.*, 88(1): 111-119.

Ruiz-Fernández, A. C., C. M. Agraz-Hernández and J. A. Sanchez-Cabeza. 2018. Sediment geochemistry, accumulation rates and forest structure in a large tropical mangrove ecosystem. *Wetlands*, 38: 307-325.

Saravanakumar, A., M. Rajkumar, J. Sun, J. S. Serebiah and G. A. Thivakaran. 2009. Forest structure of arid zone mangroves in relation to their physical and chemical environment in the western Gulf of Kachchh, Gujarat, northwest coast of India. *J. Coast. Conserv.*, 13: 217-234.

Singh, H. S. 2000. Mangroves in Gujarat: Current status and strategy for conservation, GEER Foundation Gandhinagar, India. 128 pp.

Singh, J. K. 2020. Structural characteristics of mangrove forests in different coastal habitats of Gulf of Khambhat arid region of Gujarat, west coast of India. *Heliyon*, 6(8): e04685.

Sitoe, A., L. J. C. Mandlate and B. S. Guedes. 2014. Biomass and carbon stocks of Sofala Bay Mangrove. *Forests*, 5(8): 1967-1981.

Srivastava, P. K., A. Mehta, M. Gupta, S. K. Singh and T. Islam. 2015. Assessing impact of climate change on Mundra mangrove forest ecosystem, Gulf of Kutch, western coast of India: a synergistic evaluation using remote sensing. *Theor. Appl. Climatol.*, 120: 685-700.

Thivakaran, G. A. 2017. Mangrove restoration: An overview of coastal afforestation in India. In: Wetland Science: Perspectives from South Asia (Eds.). A. B. Prusty, R. Chandra, and P. A. Azeez. Springer India, p. 501-512.

Thivakaran, G. A., S. B. Sharma, A. Chowdhury and A. Murugan. 2018. Status, structure and environmental variations in semi-arid mangroves of India. *J. For. Res.*, 31: 163-173.

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: 37-44.

Upadhyay, V. P. and P. K. Mishra. 2014. An ecological analysis of mangroves ecosystem of Odisha on the eastern coast of India. *Proc. Indian Natl. Sci. Acad.*, 80 (3): 647-661.

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.

Zamprogno, G. C., M. M. P. Tognella, V. D. S. Quaresma, M. B. D. Costa, S. S. Pascoalini and G. F. D. Couto. 2016. The structural heterogeneity of an urbanised mangrove forest area in southeastern Brazil: Influence of environmental factors and anthropogenic stressors. *Braz. J. Oceanogr.*, 64 (2): 157-172.

