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Floristic diversity, structure, and carbon stock of mangroves in a tropical lagoon ecosystem at Setiu, Malaysia

MOHAMMAD AHSANUL ISLAM[1,2], MOHD HANAFI IDRIS[1,♥], MD KHURSHID ALAM BHUIYAN[3], MOHD SHAROL ALI[1], MOHAMAD TARMIZI ABDULLAH[1], ABU HENA MUSTAFA KAMAL[1]

[1]Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu. Kuala Nerus, 21030 Terengganu, Malaysia.
Tel./fax.: +60-9-668 4100, ♥email: mohdhanafiidris@gmail.com
[2]Department of Oceanography, Shahjalal University of Science and Technology. Sylhet 3114, Bangladesh
[3]Department of Physical Chemistry, Faculty of Marine and Environmental Science, University of Cadiz. Poligono Rio San Pedro s/n, 11510, Puerto Real, Spain

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Abstract. *Islam MA, Idris MH, Bhuiyan MKA, Ali MS, Abdullah MT, Kamal AHM. 2022. Floristic diversity, structure, and carbon stock of mangroves in a tropical lagoon ecosystem at Setiu, Malaysia. Biodiversitas 23: 3685-3696.* Mangroves in lagoon habitats play an important role in ecosystem functions. Many studies on mangrove habitats are available in coastal habitats However, the information on the lagoon ecosystems in tropical climates is scanty, especially regarding their vegetation and carbon storage. This study was carried out to assess the status of species diversity, composition, zonal structure, and carbon storage of mangrove vegetation in Setiu lagoon, Malaysia. We used the transect line plot method in representative landward and small fringe island areas. The results showed that the floristic diversity of mangroves comprised 18 true mangroves and 11 associates, of which *Avicennia rumphiana* and *Ceriops decandra* were listed as threatened by IUCN. The stem density and basal area ranged from 1533 to 3800 individuals. ha^{-1} and 18.98-37.97 m^2 ha^{-1}, respectively. The mean tree diameter was 9.80 ± 2.85 cm, with a tree height of 10.35 ± 2.14 m. The mangrove species with the highest importance value index (IVI) was *Rhizophora mucronata* with 134.86, while the lowest was *Acanthus ebracteatus* with 13.23. The study revealed that small fringe islands in the lagoon were more diverse, with biodiversity index values always higher than the landward zone. Total biomass from the dominant mangrove species was estimated at 522.9 t ha^{-1} with an estimated carbon storage of 261.45 t ha^{-1} and a sequestration potential of 959.54 t CO_2 ha^{-1}. Compared to the other mangrove ecosystems elsewhere, this study recommends that the Setiu lagoon should be considered as a healthy and newly generated mangrove forest. Therefore, proper monitoring is needed to ensure mangrove ecosystem health and function.

Keywords: Carbon sequestration, diversity index, lagoon ecosystem, species composition, tree biomass, zonation

INTRODUCTION

Mangroves are halophytic shrubs and trees that grow at the interface between land and sea in the tropical and sub-tropical regions of the world, covering at least 15.2 million hectares and distributed in 123 countries (Billah et al. 2022a). The geographic position of mangrove forests has made them ecologically the most important zone for the floral and faunal diversity with distinct characteristics (Shah et al. 2016). A total of 70 true mangrove species from 11 families have been recorded around the world (Wang et al. 2003a) and these species are subdivided into three categories, namely true mangroves, mangroves, and mangroves associate (Nor et al. 2022; Wan Juliana et al. 2014). More than one-third (37%) of mangroves are distributed in Asia, and the rest of the mangroves are in North and South America (27.2%), Africa (21%), and Australia (12.4%) (FAO 2007; Sandilyan and Kathiresan 2012). Malaysian mangroves cover 0.580 million ha (Shah et al. 2016) and this contributes to approximately 12% of Southeast Asia's mangrove area, which is distributed along the coasts of Sabah (57%), Sarawak (26%), and Peninsular Malaysia (17%) (Goldberg et al. 2020). Besides their importance in terms of biodiversity, mangroves play an important role in nutrient cycling (Abu Hena et al. 2020) by providing nutrients and flux of organic particles into the aquatic ecosystem (Mahmood et al. 2003). Tropical mangroves also act as an important regulatory service for climate change mitigation (Donato et al. 2011), since they can sequester and store more carbon than terrestrial forests and other ecosystems globally (Alongi 2012; Alemaheyu et al. 2014).

Based on some recent reviews, there has been an increasing interest in studying ecosystem services, especially carbon sequestration in the blue carbon habitats (Billah et al. 2022b; Cadier et al. 2020). The estimation of above-ground biomass (ABG) on a large scale is crucial for better understanding its role in climate change mitigation (Lupembe and Munishi 2019; Suwa et al. 2021). Further, species composition, stand structure, and biomass studies are of increasing interest in sustainable forest management and carbon sequestration (Gonçalves 2018) and are relevant to the local and global scale. The emerging concern for mangroves is particularly important considering the high rate of deforestation and degradation of global mangroves since 62% of mangroves have been lost worldwide from 2000 to 2016 (Goldberg et al. 2020). They are facing continuous pressure due to overexploitation, coastal aquaculture, overfishing, and different anthropogenic activities (Hadiana and Samosir 2015; Sreelekshmi et al. 2018). Thus, estimating the changes in mangrove parameters over time is needed to understand the mangrove function and the dynamics of changes.

Lagoons are shallow coastal habitats separated by sand bars or rocks, and they are also protected from wave action. Therefore, the morpho-dynamics of such ecosystems are different compared to the open or estuarine coasts hosting mangroves. A lagoon ecosystem can provide more ecological and economic services than other coastal and freshwater ecosystems. Mangroves in the lagoon ecosystem are very rich in terms of nutrient depositors due to their low energy forces and actions, confined area, as well as strategic location. Lagoon mangroves and seagrass habitats provide a safe refuge as nurseries and feeding grounds for many commercially important finfish and shellfish (Kennish and Paerl 2010). Many fish species have adapted to spawning in marine coastal waters, while juveniles migrate into the lagoons to feed and grow in their shelter (de Wit 2011).

Setiu is a lagoon ecosystem composed of mangroves with small patches of seagrass beds situated on the east coast of Malaysia and plays many significant roles in the coastal community's life and livelihoods. Studies on the lagoon mangrove ecosystems and forest structures along with carbon sequestration are very few to date in this region (Salim et al. 2020; Salim et al. 2015; Ibrahim et al. 2019; Mahmud and Viez 2015; Suratman et al. 2017; Mohd Azmi 2014). Aiming to fulfill the data gap, the present study was an attempt to improve our understanding of floristic diversity, zonation pattern, and total carbon content of mangroves in Setiu Lagoon, east coast of Peninsular Malaysia. The outcomes of this study would be helpful in monitoring and modeling this valuable ecosystem. Further, carbon sequestration data provided in the present investigation would be valuable to enrich a global database on the contribution of mangroves to carbon sequestration.

MATERIALS AND METHODS

Study area description

This study was conducted in the Setiu Lagoon, which is situated on the east coast of Peninsular Malaysia in the South China Sea, covering an area of 23,000 ha of land and 880 ha of water bodies (Nakisah and Fauziah 2003) (Figure 1) and comprises riparian forests lining the riverbanks, peat swamps, mangroves, brackish water lagoons with vegetated small fringe islands, sand islands, seagrass beds, and sandy beaches. The total length of this lagoon is almost 14 km parallel to the beach, connecting with a narrow inlet (Salim et al. 2015).

Sampling area design and plot establishment

The field study was conducted from September to December 2021. The transect line plots method was used for sampling area design (English et al. 1997). Two categories of plots (landward and fringe islands) were selected to collect data and for analysis based on representative areas. As plot designs, four stations (i.e., A- 5° 41´ 43.65´´ N, 102° 41´ 36.68´´ E; B- 5° 40´ 58.8´´ N, 102° 42´ 30.33´´ E; C- 5° 37´ 49.82´´ N, 102° 46´ 33.72´´ E; D- 5° 37´ 32.94´´ N, 102° 47´ 02.45´´ E) and eight transects plots were chosen (Figures 1 and 2). Eight transects lined with three individual plots were established vertically from the riverbank to observe the species diversity and forest structure. In each plot, three subplots were designed for trees (10m×10m), saplings (5m×5m) and seedlings (2m×2m) in the same stand.

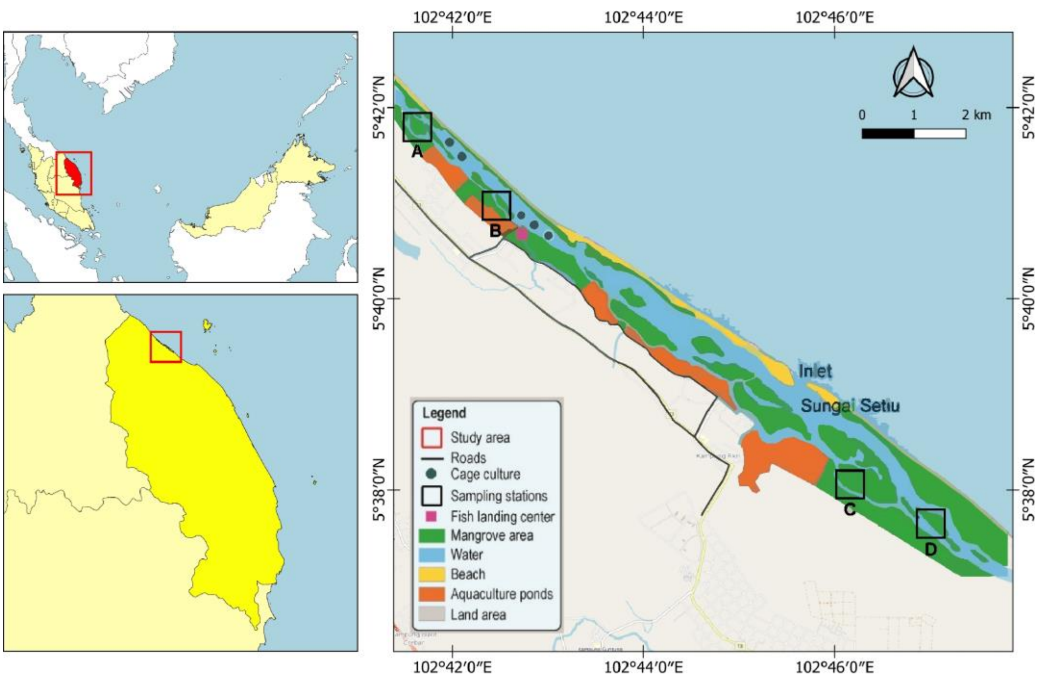

Figure 1. Location of the study area showing four sampling stations at Setiu Lagoon, east coast of Peninsular Malaysia

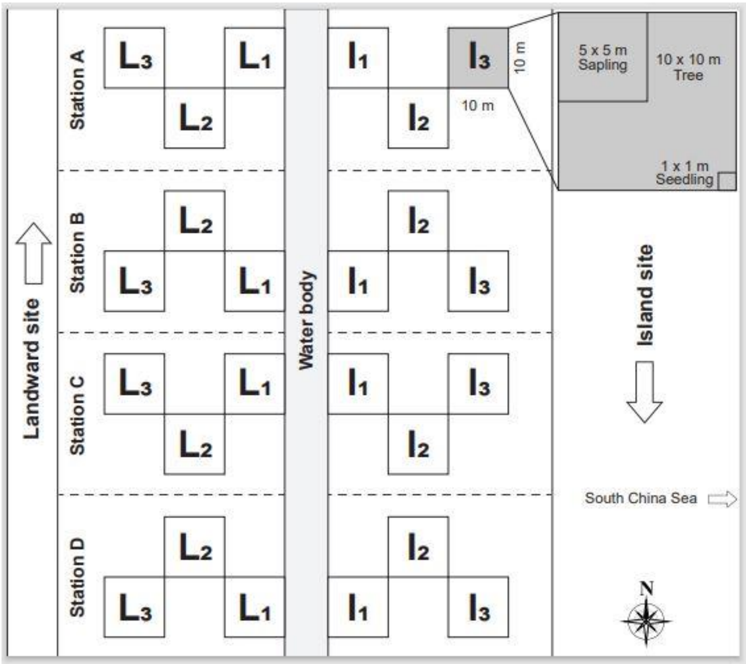

Figure 2. Schematic diagram showing four different stations and quadrates used for sampling in the study area

In particular, the number of trees, the diameter of breast height (DBH, at 1.37 m), and tree height were recorded in situ. Plants having a DBH of >5cm were recorded as trees, <3cm as seedlings, and 3-5 cm as saplings (Kathiresan 2000). Tree DBH data was recorded using a measuring tape in cm, while the height of the tree was measured using clinometers (Laser Ace 300). Simultaneously, light intensity was measured in situ using a digital light meter (Kyoritsu 5202). Mangrove soils from different plots were collected and brought to the lab for texture analysis using a hydrometer (ZEAL D4040) following Ashworth et al. (2001). For porewater, a small hole was made by digging the soil and waiting until water was stored in the hole. Some essential in situ data (salinity, pH, and temperature) were recorded from the respective plot by using Multi-parameter (VT878).

Mangrove species identification

Species nomenclature in each plot was done following the Handbook of Mangroves in the Philippines- Panay (Primavera et al. 2004), and all the identified species nomenclature was also checked by the Mangrove: Guidebook for Malaysia (Shin et al. 2015). Taxonomic classification was checked in the International Plant Naming Index (IPNI 2015).

Species composition, importance value index, and diversity indices

Collected data was analyzed to describe mangrove structural compositions (i.e., density, basal area, DBH, and height) and structural parameters (i.e., relative density, relative frequency, and relative dominance) following English et al. (1997). The importance value was also determined following Cintron and Novelli (1984). The equation of such parameters is as follows:

Basal area (cm^2) = πx$(DBH/2)^2$

Stand basal area (m^2 ha^{-1}) = Sum of basal areas/area of the plot

Density (no. ha^{-1}) = (No. of living stems in a plot x 1,000)/area of plot

Relative density = (Density of a species/total density of all species) x 100

Relative frequency = (Frequency of a species/total frequency of all species) x 100

Relative dominance = (Total basal area of a species/total basal area of all species) x 100

Importance value = Relative density + Relative frequency + Relative dominance

The vegetation diversity was calculated using the Shanon diversity index (H'), Margalef richness (d'), Pielou evenness (J'), and Simpson's index (λ') using the Paleontological Statistical Software (PAST) ver 4.07 (Hammer et al. 2001).

Using the importance value index (IVI), we calculated the species diversity (Cintron and Novelli 1984). Dominant species were defined based on frequency. The diversity indices were determined following the Shanon-Wiener information function. Shanon and Weiner (1963) diversity index consider both the number of species and the distribution of individuals among the species.

$$H' = -\sum Pi \times \log_e Pi$$

Where:

P = The proportion of individuals in the i species

Pi = The proportion of individuals in the i^{th} species

$$Pi = \frac{Number\ of\ individuals\ in\ each\ species\ (ni)}{Total\ number\ of\ individuals\ in\ all\ species\ in\ a\ sample\ (N)}$$

$\log_e Pi = Proportion\ of\ individuals\ based\ on\ natural\ log$

Margalef index (D) (Margalef 1968) was used to determine the number of species richness by the following formula:

$$d = (S - 1/\log_e N)$$

Where,
N= number of individuals in the sample
S= Number of species

The relative abundance of species (evenness) index of Pielou (1966) was determined following the formula

$$J = H'/\log_e S$$

Where,
H'= Shannon's diversity index
S= Number of species

Species dominance was measured following Simpson's index (Simpson, 1949). The formula of Simpson's index was:

$$D = {}^{1}/_{\lambda}$$

Where,
$\lambda = \sum Pi2$

All diversity calculations were based on the use of natural log ($\log_e$)

Biomass calculation

The above-ground and below-ground biomass of mangrove vegetation were calculated following allometric equations established by Komiyama et al. 2005 (Table 1). The above-ground and below-ground biomass values were converted to biomass per ha by dividing the total biomass of a species by the total plot area (0.1 ha) of each station: Biomass per ha (t ha^{-1}) = Total biomass/0.1 ha

The carbon content and the calculation of carbon dioxide (CO_2) absorption by the mangrove vegetation were calculated by the following equations (IPCC, 2014):

Carbon content = Biomass x 50%
CO_2 = (Mr. CO/Ar. C) × Carbon content

Where:
CO_2 = Carbon dioxide uptake
Mr. = Relative molecule
Ar. = Relative atom

Statistical analysis

All statistical analysis was carried out using the PAST software v4.03 (Hammer et al. 2001). Stand structure and biomass were calculated as the mean and standard error (SE). Euclidean similarity index (distance matrix) was obtained between every pair of species (Abonyi and Feil 2007). One-way analysis of variance (ANOVA) was used to compare differences in ecological parameters and stand structure among the study areas. Post-hoc Tukey (HSD) tests were used to detect differences in treatments when differences were found at a significant level ($p > 0.05$).

RESULTS AND DISCUSSION

Ecological parameters

The soil pH in each station ranged from 4.40 to 5.90 with an average value of 5.08 ± 0.45 (Figure 3). The soil was mostly sandy in all stations, and the average values of sand, silt, and clay were 81.79 ± 5.85%, 8.08 ± 3.35%, and 10.20 ± 4.98% respectively. The mean porewater salinity was 19.05 ± 0.98 psu, with a higher value of 21.63 ± 0.20 psu on the fringe island at station B. The highest soil temperature (30 ± 0.57 °C) was found in station D due to lower forest density with an average of 28.75 °C. The highest light intensity was obtained from station D (fringe island area) with a value of 3.24 ± 0.76 klx. The mean light intensity in all stations was recorded at 1.66 ± 0.92 klx. Considering eight substations (2 substations × 4 sites), there was high variability in light intensity index ($F=4.57$; $p=0.005$), soil pH ($F=2.96$; $p=0.03$), soil temperature ($F=3.83$, $p=0.012$), porewater salinity ($F=132.7$, $p<0.0001$), porewater pH ($F=6.30$, $p=0.001$), sand ($F=7.38$, $p<0.0001$), silt ($F=6.06$, $p<0.0014$), clay ($F=10.65$, $p<0.001$) (Figure 3).

In the tropical region, climatic factors such as soil nutrients, soil pH, soil temperature, soil texture, porewater salinity, inundation time, and sedimentation rate are almost the same for the mangrove ecosystem (Hoque et al. 2015). Our results indicated that the mangrove species tended to inhabit different areas with different ecological functions. In Setiu lagoon, stations A and B were mostly dominated by *R. mucronata* and co-dominated by *R. apiculata*, while stations C and D were dominated by *N. fruticans*. It is also the case that fringing islands have higher diversity than the landward zone. This phenomenon could be due to the different ecological variations like salinity and soil texture. Usually, *N. fruticans* mangrove is dominant in the riverine ecosystems where freshwater input is high, and it is the case for Setiu lagoon. Shah et al. (2016) also revealed that *N. fruticans* colonized on the bank of an estuary where fresh water was continuously discharged into the sea.

Species composition

A total of eighteen true mangrove species from ten families and eleven mangrove associates from nine families were identified from the mangrove lagoon of Setiu, on the east coast of Malaysia (Table 2). Six species (*R. apiculata*, *R. mucronata*, *B. gymnorrhiza*, and *Aviccenia alba*, *Sonneratia alba*, and *N. fruticans*) were found to be dominant in all study sites. This finding is much higher than other recent studies on mangrove-dominated coastlines in Malaysia, i.e., 9 species by Mahmud and Viez (2015); 9 species by Shah et al. (2016); and 14 species by Zakaria et al. (2018). Mangrove *R. apiculata* is widely distributed in the coastal region of Malaysia, as reported elsewhere (Wan Juliana et al. 2014; Hoque et al. 2015).

Studies by Mahmud and Viez (2015) also reported *R. apiculata* as a dominant species in the Setiu lagoon. This study revealed that the highest and second highest species abundance were in the Rhizophoraceae and Acanthaceae families, respectively. For mangrove associates, the Fabaceae family was mostly dominant in all stations. It has been reported that, genetically, Rhizophoraceae species have a strong adaptive capacity to extreme environmental conditions (Tomlinson 2016), and our findings are also in line with previous reports that the Rhizophoraceae is the most dominant family in these mangrove lagoon ecosystems. According to the IUCN Red List category (ver. 3.1, 2019), except for *C. decandra* (NT) and *A. rumphiana* (VU), all identified species were categorized as Least Concern (LC).

Table 1. The allometric equation and density of different mangrove species for biomass estimation

Species	Above Ground Biomass (AGB) (t/ha)	Below Ground Biomass (BGB) (t/ha)	ρ (wood density) (g/cm3)
Rhizophora apiculata	$W_{top} = 0.170\rho D^{246}$ [1]	$W_R = 0.199\rho^{0.899}D^{2.22}$ [1]	0.770 [1]
Rhizophora mucronata	$W_{top} = 0.170\rho D^{246}$ [1]	$W_R = 0.199\rho^{0.899}D^{2.22}$ [1]	0.867 [2]
Bruguiera gymnorrhiza	$W_{top} = 0.251\rho D^{246}$ [1]	$W_R = 0.199\rho^{0.899}D^{2.22}$ [1]	0.699 [1]
Sonneratia alba	$W_{top} = 0.251\rho D^{246}$ [1]	$W_R = 0.199\rho^{0.899}D^{2.22}$ [1]	0.475 [1]
Avicennia alba	$W_{top} = 0.251\rho D^{246}$ [1]	$W_R = 0.199\rho^{0.899}D^{2.22}$ [1]	0.506 [1]

Note: References (in square parentheses): 1 = Komiyama et al. (2005), and 2 = Simpson (1996)

Table 2. Identified mangrove species from Setiu Lagoon, east coast of Peninsular Malaysia

Family	Species	Local name	Intertidal distribution			Conservation Status
			LZ	MZ	UZ	
True mangrove						
Rhizophoraceae	Rhizophora apiculata Blume	Bakau minyak, Bakau tandok		√		LC
	Rhizophora mucronata Lamk.	Bakau belukap, Bakau gelukap		√	√	LC
	Bruguiera gymnorrhiza (L.) Lamk.	Tumu merah, Berus merah,	√	√		LC
	Bruguiera cylindrica (L.) Bl.	Berus-berus, Berus putih	√	√		LC
	Bruguiera parviflora (Roxb.) W. & A. ex Griff	Lenggadai, Mengkadai		√		LC
	Ceriops decandraa (Griff.) Ding Hou	Tengal, Tengar	√	√		NT
	Ceriops tagal (Perr.) C.B. Rob.	Tengal, Tengar	√	√		LC
Avicennaceae	Acanthus ebracteatus Vahl.	Jeruju (hitam)	√			LC
	Avicennia alba Blume	Api-api Putih		√	√	LC
	Avicennia officinalis L.	Api-api Ludat		√		LC
	Avicennia rumphianaa Hall. F.	Api-api Bulu		√		VU
Meliaceae	Xylocarpus granatum Koen.	Niri, Nyireh, Nyiri	√	√		LC
Lythraceae	Sonneratia alba J.E. Smith	Perepat, Pedada, Pidada			√	LC
Arecaceae	Nypa fruticans Wurmb.	Nipah	√	√		LC
Malvaceae	Heritiera littoralis Dryand.	Dungun laut	√			LC
Combretaceae	Lumnitzera racemosaa Willd.	Teruntum putih	√	√		LC
Myrsinaceae	Aegiceras corniculatuma (L.) Blanco	Kacang-kacang; Kuku helang			√	LC
Euphorbiaceae	Excoecaria agallocha L.	Buta-buta, Kayu buta-buta	√	√		LC
Mangrove associate						
Lecythidaceae	Barringtonia racemosa (L.) Spreng	Putat ayam	√	√		LC
Fabaceae	Cynometra ramiflora L.	Kateng, Katong laut	√	√		LC
	Intsia bijugaa (Colebr.) Kuntze	Merbau ipil	√			VU
	Derris trifoliata Lour.	Tuba laut	√	√		NE
Rubiaceae	Oxyceros longiflorus (Lam.) T.Yamazaki	Akar berdara laut	√			NE
Pandanaceae	Pandanus tectorius Sol.	Pandan laut	√			LC
Sapotaceae	Planchonella obovata (R.Br.) Pierre	Menasi, Misi	√			NE
Malvaceae	Hibiscus tiliaceus L.	Ambaru,Baru, bebaru	√			LC
Sapindaceae	Allophylus cobbe L. (Reausch)	Kasai Daun Kecil	√			LC
Apocynaceae	Cerbera odollama Gaerth.	Pong Pong	√	√		LC
Arecaceae	Calamus erinaceus (Becc.) J. Dransf.	Rotan Bakau	√			LC

Note: LZ = Lower zone, MZ = Middle Zone, UZ = Upper zone); IUCN Red List Threatened categories: VU = Vulnerable, NT = Near Threatened, LC = Least Concern, NE = Not Evaluated. aRecorded from outside of quadrate

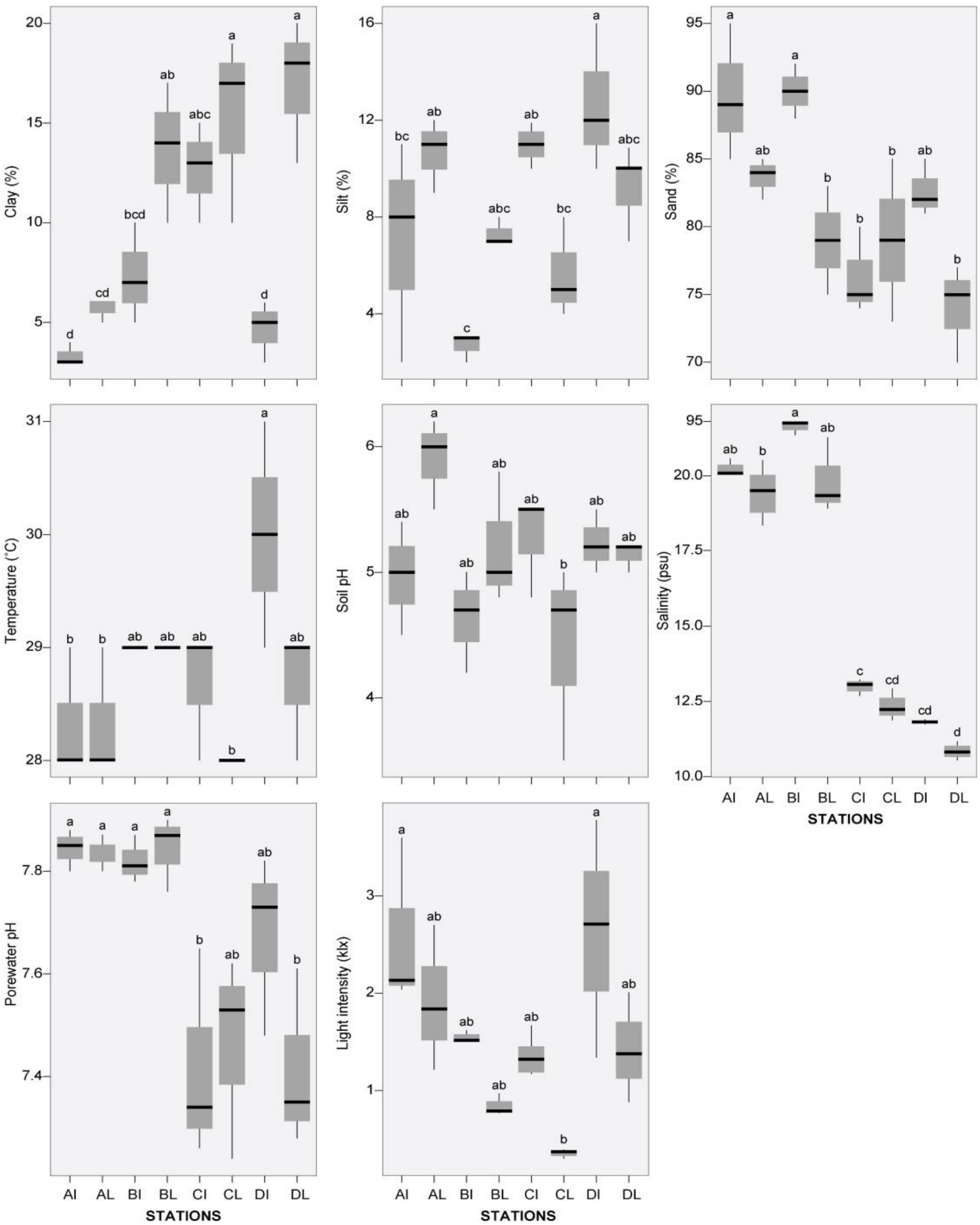

Figure 3. Variations of A. Light intensity (klx), B. Soil Temp. (°C), C. Soil pH, D. Porewater salinity (psu), E. Porewater pH, F. Sand (%), G. Silt (%), and H. Clay (%) in different stations (I = Fringe Island area, L = Landward area) at 5% level of significance using One-way ANOVA Post-hoc Tukey (HSD) test

Zonation pattern of mangroves

The zonation pattern of mangroves was different across stations (Figure 4). In general, the fringe island areas were the most diverse and dense compared to the landward areas. Fringing areas were less disturbed, and the ecological parameters were better in health than the landward areas. This study found that stations C and D were dominated by *N. fruticans* while stations A and B were dominated by *R. mucronata*. The landward lower zone of the lagoon was grouped by *R. mucronata*, *N. fruticans*, and *A. Alba*, while in the higher zone they were dominated by *E. agallocha*, *X. granatum*, and *H. littoralis* species. On the other hand, the lower zone of the fringe island was assembled by *R. mucronata*, *S. alba*, and, in some cases, by *N. fruticans* in stations C and D, and the upper zone was by *L. racemosa*, *E. agallocha*, and *H. littoralis* species. Coincidentally, the middle zone between the two areas was mostly dominated by *R. apiculata*, *B.*

gymnorrhiza, *B. cylindrica*, *X. granatum*, and *C. tagal*. Hydrological parameters may affect mangrove plant distribution (Crase et al. 2013; Leong et al. 2018) and also have species-specific hydroperiod tolerance thresholds that are mostly resolute by surface elevation (Ball and Pidsley 1995). For example, *A. marina* can thrive in high salinity and high-temperature areas (Bagust and Tout-Smith 2005), and *Rhizophora* spp. can adapt to extreme mangrove environments, which are widely distributed all over the world (Tomlinson 1986). Hence, it can be assumed that the ecological conditions have a direct effect on the growth and distribution of mangrove forests.

Structural analysis

The mean tree density of the Setiu mangrove forest was 2887.5 ± 727.67 individuals. ha^{-1} (Table 3). The highest density (3800 ± 700 individuals. ha^{-1}) was recorded from the fringe island of station B, while the lowest density (1533.33 ± 351.18 individuals. ha^{-1}) was recorded from the landward position of station C. The mean sapling density was 2092 ± 1768 individuals. ha^{-1}, with the highest mean sapling density (6166.66 ± 5052.06 individuals. ha^{-1}) found in the landward position of station D. The overall mean density of seedlings was 5100 ± 4498.81 individuals. ha^{-1}, with the highest seedling density of 7766.66 ± 4895.23 individuals. ha^{-1} from the landward position of station B and the lowest was 866.66 ± 568.62 individuals. ha^{-1} recorded from the fringe island of station C. The mean values of DBH and basal area were 9.80 ± 2.85 (cm and 24.70 ± 18.11 m^2 ha^{-1}, respectively. The maximum tree height was recorded at 14.65 ± 1.63 m from the landward position of station A.

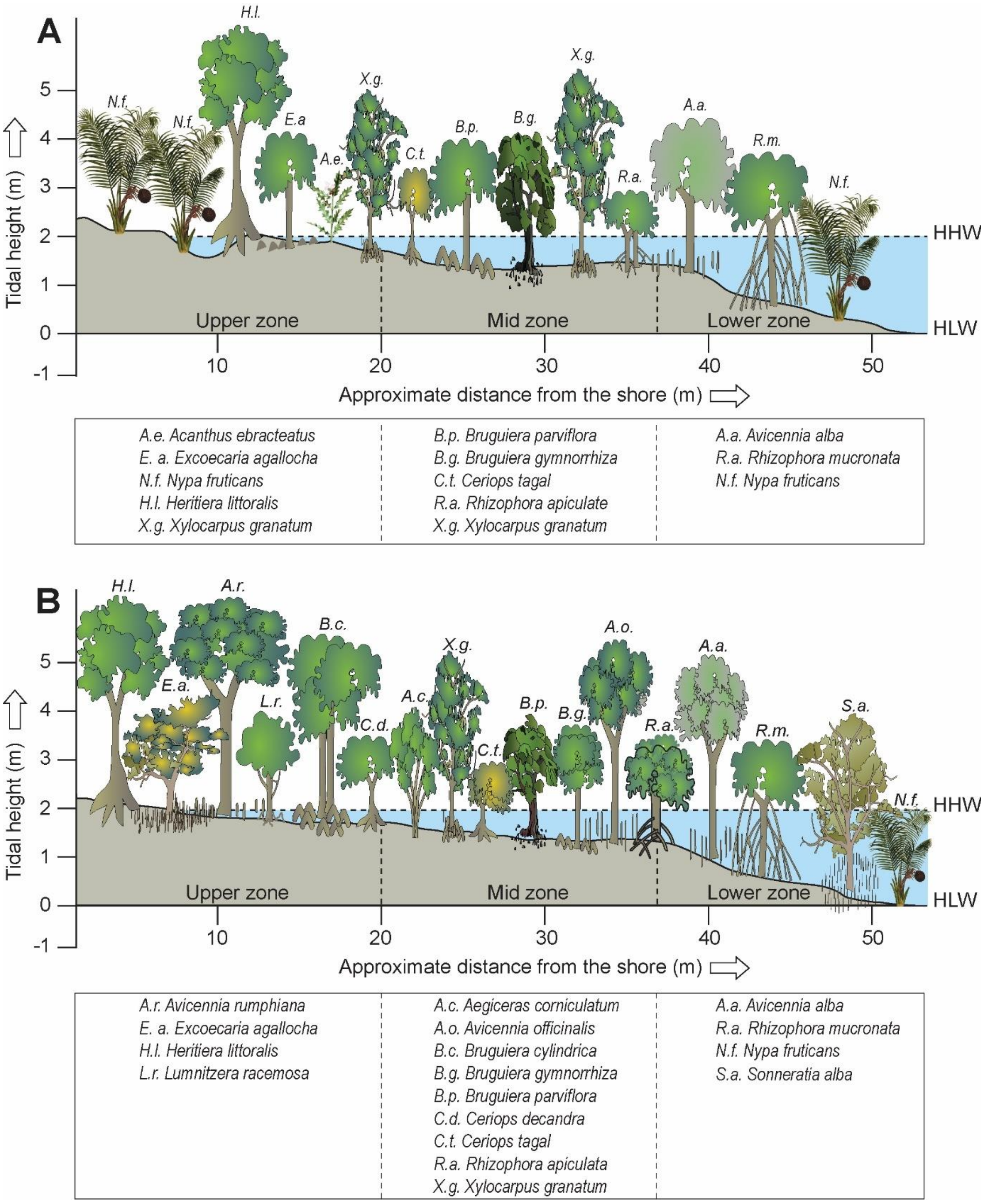

Figure 4. Cumulative zonation pattern of mangrove species in the landward site (A) and fringe island site (B) based on the present study

Table 3. Mean value (± standard deviation) of structural composition of tree, sapling, and seedling of mangroves at Setiu Lagoon, east coast of Peninsular Malaysia

Station	Quadrate	Tree (individuals. ha^{-1})	Sapling (individuals.ha^{-1})	Seedling (individuals. ha^{-1})	Tree diameter (cm)	Basal area (m2. ha^{-1})	Height (m)
A	I	3100 ± 1400	1400 ± 300	1200 ± 692.82	9.23 ± 1.77	22.62 ± 13.53	8.73 ± 3.56
	L	2566.66 ± 960.90	800 ± 608.27	433.33 ± 493.28	9.28 ± 1.99	18.98 ± 13.99	14.65 ± 1.63
B	I	3800 ± 700	2966.66 ± 2200.75	4000 ± 5819.79	8.91 ± 3.54	26.39 ± 20.94	8.68 ± 2.12
	L	2600 ± 984.89	1400 ± 1135.78	7766.66 ± 4895.23	7.01 ± 4.04	18.15 ± 19.29	11.11 ± 1.93
C	I	3766.66 ± 1973.15	1000 ± 854.40	866.66 ± 568.62	10.07 ± 4.41	37.97 ± 44.83	10.93 ± 2.09
	L	1533.33 ± 351.18	1466.66 ± 568.62	7300 ± 3750.99	12.21 ± 3.77	19.53 ± 11.94	9.71 ± 1.98
D	I	2733.33 ± 1040.83	1533.33 ± 1331.66	5566.66 ± 3524.67	10.13 ± 1.68	21.48 ± 7.00	8.69 ± 3.02
	L	3000 ± 984.88	6166.66 ± 5052.06	13666.66 ± 2433	11.60 ± 1.61	32.46 ± 13.34	8.14 ± 2.98
	Mean	2887.5 ± 727.67	2091.66 ± 1768.39	5100 ± 4498.81	9.80 ± 2.85	24.70 ± 18.11	10.35 ± 2.14

Note: I= Island site, L= Landward site

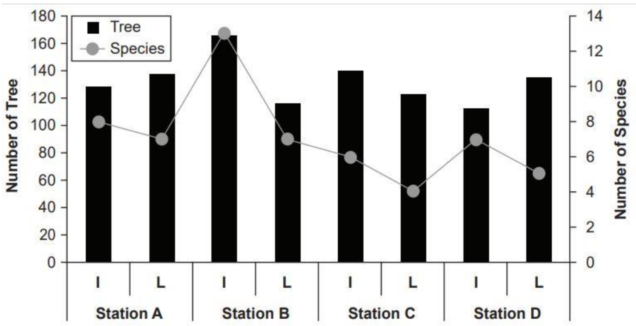

Figure 5. Tree abundance with the number of species identified from the different stations

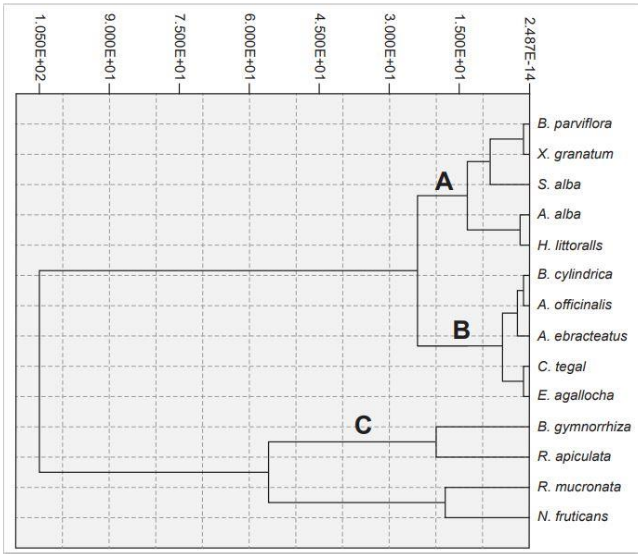

Figure 6. Hierarchical cluster of mangrove vegetations plot based on species density (no. ha^{-1}). Dendrogram by single linkage, Euclidean similarity index

This study was comparable with the reported value (2175 individuals. ha^{-1}) for Kuala Selangor mangrove forest (Hossain 2004) and 1982 individuals. ha^{-1} from the Sibuti mangrove forest (Shah et al. 2016). The mean density of saplings and seedlings was 2092 individuals. ha^{-1} and 5100 individuals. ha^{-1}, respectively, from the studied lagoon. According to Gan (1995), a seedling size of 5000-10,000 individuals. ha^{-1} indicates healthy regeneration of a mangrove forest, hence Setiu mangrove lagoon has good regeneration potential. The mangrove associates also have little abundance with the small basal area that was not counted in this study; a similar observation has also been made from the mangrove forest at Samatan, Sarawak, Malaysia (Ashton and Macintosh 2002). The reported values of forest density (ha^{-1}) and basal area (m^2 ha^{-1}) from the mangrove forest were generally higher than the present study (Table 4).

Tree abundance and species clustering

The maximum number of trees (165 individuals) and species (13 species) were found from the fringe island of station B, while the lowest number of trees (122 individuals) and species (4 species) were found from the landward position of station C (Figure 5). Euclidean similarity index cluster analysis found three distinct clusters (Figure 6), i.e.: (i) cluster A with moderately common plant species (namely *B. parviflora, X. granatum, S. alba,* and *H. littoralis)*; (ii) cluster B, with sparsely distributed plant species; and (iii) cluster C with highly abundant four plant species such as *B. gymnorrhiza*, *R. apiculata*, *R. mucronata*, and *N. fruticans*; this group can be termed as "most common" plant group. The cluster followed the pattern of species dominance and species clustering in each station of the study area. Cluster C was considered as highly dispersedly distributed (below 60%) in the area of interest. Cluster B was comprised of cluster A, which was distributed regarding the occurrence (below 15%). Finally, cluster A was considered moderately common (below 30%), comprised of clusters B and C.

Table 4. Comparison of Setiu Lagoon, east coast of Peninsular Malaysia mangroves with the other mangroves of the world

Latitude	Density (ha^{-1})	Basal area (m2. ha^{-1})	Major species	Location	Authors
3	1600-2340	171.1-201.8	*R. apiculata*	Sibuti, Malaysia	Shah et al. (2016)
4	158-6000	1.2-40.8	*S. alba*	Zambezi delta	Trettin et al. (2016)
4	600-1700	0.47-2.9	*R. mangle*	Brazil	Maia and Coutinho (2012)
6	790-1360	1.4-49	*N. fruticans* and *S. caseolaris*	Kelantan Delta, Malaysia	Satyanarayana et al. (2010)
5	2175	19.18	*B. parviflora*	Malaysia	Hossain (2004)
7	10-2880	0.02-10.28	*A. corniculatum*	Java, Indonesia	Hinrichs et al. (2009)
8	10-528	0.001-0.016	*R. mucronata*	Sri Lanka	Perera et al. (2013)
8	29-19386	-	*A. marina*	Ashtamudi, Kerala	Sreelekshmi et al. (2017)
9	7680-11760	0.16-9432	*A. officinalis*	Cochin, Kerala	Rani et al. (2016)
9	1678	20.33	*A. officinalis*	Kerala	George et al. (2019)
9	10-13846	0.02-20.19	*A. officinalis*	Kerala	Sreelekshmi et al. (2017)
11	1641	-	-	Pichavaram, Tamil Nadu	Kathiresan et al. (2016)
11	250-32140	-	*R. mucronata*	Andaman	Das et al. (2014)
11	500-2400	-	*R. apiculata*	Andaman & Nicobor	Ragavan et al. (2015)
11	1252-2200	30.8-59.6	*R. apiculata*	Andaman	Kiruba-Sankar et al. (2017)
20	2012-3586	3.17-7.5	*H. fomes* and *E. agallocha*	Bhitarkanika, Orissa	Upadhyay & Mishra (2014)
21	912-7031	4.2-19.2	*A. alba*	Sundarbans	Joshi and Ghose (2003)
23	1820-4325	-	*A. marina*	Kachchh, Gujrat	Sawale and Thivakaran (2013)
5	1533-3800	18.98-37.97	*R. mucronata*, *B. gymnorrhiza*	Setiu Lagoon, Malaysia	*Present study*

Importance value index (IVI) of species

This study found that *R. mucronata* stands were recorded for the highest IVI value (134.86), whereas the lowest value was 13.23 for *A. ebracteatus.* The data also showed that *R. mucronata* had the highest values of relative density (23.66%) and relative dominance (23.70%). The lowest values of relative density and relative dominance were 0.29% and 0.44% respectively. The relative frequency of true mangrove species was maximum (87.5%) for *R. mucronata*, followed by *N. fruticans* (75%), and the other three species (*B. gymnorrhiza*, *X. granatum*, and *C. tagal*) was 62.5% (Table 5) which is closer to the findings of Norhayati et al. (2009) from Selangor. According to Wah et al. (2011), the importance value index for *R. mucronata* was similar (173.6) to the present findings in Semporna mangrove forest, Sabah. This confirms that the similarity between the species composition and diversity index could be the same due to the similar position in the tropical region.

Diversity indices

The Shannon diversity index and Simpson dominance index for station B ranged from 1.73 to 1.79 and 0.46 to 0.81 respectively (Table 6). That was the highest value and indicated a very high level of mangrove species diversity in station B. Furthermore, higher values of Pielou's evenness index (0.69-0.89) indicated the mangrove species distribution among the stations. The fringe island area of station B exhibited maximum species diversity (1.79) and the island area represented the highest value of species richness (0.79). On the other hand, the study revealed that the lowest values of species diversity (0.74), richness (0.35), evenness (0.46), and dominance (0.41) were in the landward position of station D. The H´ and J´ values were found to be 1.79 and 0.89, respectively, while d´ (0.79) was higher in both stations A and B. These index values are most similar to those of the Sematan mangrove forest (H´=1.42, d´=1.50, and J´=0.68) reported by Ashton and Macintosh (2002).

Biomass estimation and carbon content

The study found the maximum mean value of DBH (15.73 ± 3.26 cm) was for *A. alba* and the lowest mean value (8.33 ± 1.38 cm) was for *B. gymnorrhiza*. Likewise, the highest (160.56 t ha^{-1}) and the lowest (55.41 t ha^{-1}) total biomass were found for *A. alba* and *B. gymnorrhiza*, respectively (Table 7). However, the average values of DBH, tree height, and basal area were comparatively lower than those in the Sibuti mangrove forest (DBH, 24.10 ± 13.90 cm; height, 15.18 ± 5.09 m; and basal area, 176.13 ± 12.73 m^2 ha^{-1}) and Awat Awat mangrove forest, Sarawak (14.45 ± 0.375 cm DBH and 12.16 ± 0.217 m height) (Chandra et al. 2011). The total carbon stock of the five most dominant species was calculated to be 261.45 t ha^{-1}, and the CO_2 sequestration from the study area was 959.54 t ha^{-1} (Table 6). The total above-ground and below-ground biomass of five dominant species at Setiu lagoon were 344.32 t ha^{-1} and 178.54 t ha^{-1}, respectively. Although the tree density of *A. alba* was the lowest in the study area, the estimated total ABG (111.62 t ha^{-1}) and BGB (48.93 t ha^{-1}) were higher than the other species. At Pulau Klang, Zakaria et al. (2018) also found higher ABG (80.51 t ha^{-1}) and BGB (41.63 t ha^{-1}) for single species of *R. apiculata*. The above-ground biomass at Johor Park mangrove forest was reported to be from 133.9 to 206.93 t ha^{-1} reflecting the smaller trees (DBH, 7.95-15.73 cm) like in this study (Tan et al. 2012). The mean for ABG and BGB of *A. marina* was recorded at 71.00 ± 2.30 and 36.07 ± 0.52 Mg ha^{-1}, respectively, from Malacca, Malaysia (Azman et al. 2021).

Table 5. The structural parameters of true mangrove species (Counted in the quadrates only)

Mangrove species	Relative dominance (%)	Relative density (%)	Relative frequency (%)	Importance value index (IVI)
R. apiculata	12.59	12.57	50	75.16
R. mucronata	23.70	23.66	87.5	134.86
B. gymnorrhiza	15.55	15.53	62.5	93.58
B. parviflora	4.74	4.73	50	59.47
B. cylindrica	0.74	0.73	25	26.47
A. alba	3.11	3.10	50	56.21
A. officinalis	0.59	0.59	50	51.18
X. granatum	4.88	4.88	62.5	72.26
S. alba	6.07	6.06	50	62.13
N. fruticans	21.03	21.01	75	117.03
H. littoralis	3.41	3.40	25	31.81
C. tagal	1.62	1.76	62.5	65.45
A. ebracteatus	0.44	0.29	12.5	13.23
E. agallocha	1.47	1.62	25	27.66

Table 6. Mangrove diversity in eight sub-stations of four respective stations in Setiu Lagoon, east coast of Peninsular Malaysia

Station	Sub-station	S	H´	d´	J´	λ´
A	I	8	1.69	0.68	0.87	0.77
	L	7	1.41	0.64	0.68	0.51
B	I	13	1.79	0.79	0.89	0.81
	L	7	1.73	0.76	0.69	0.46
C	I	6	1.22	0.64	0.81	0.77
	L	4	1.13	0.61	0.68	0.56
D	I	7	1.70	0.78	0.87	0.78
	L	5	0.74	0.35	0.46	0.41

Note: S: No. of species; H´: Shannon diversity; d´: Margaled species richness; J´: Pielou's evenness; λ´: Simpson dominance; I= Island site, L= Landward site

Table 7. Mean diameter (±standard deviation) at breast height, total biomass, carbon stock and CO2 sequestration potential of dominant species of mangrove vegetation in Setiu Lagoon, east coast of Peninsular Malaysia

Mangrove species	Mean DBH (cm)	Biomass estimation (t ha^{-1})			Carbon stock (t ha^{-1})	CO_2 sequestration (t ha^{-1})
		AGB	BGB	Total		
R. apiculata	11.24 ± 1.60	50.59	33.84	84.44	42.22	154.95
R. mucronata	11.45 ± 2.42	59.68	39.27	98.96	49.48	181.59
B. gymnorrhiza	8.83 ± 1.65	37.25	18.15	55.41	27.71	101.68
A. alba	15.73 ± 3.26	111.62	48.93	160.56	80.28	294.63
S. alba	14.46 ± 4.57	85.18	38.35	123.53	61.76	226.69
Total		344.32	178.54	522.9	261.45	959.54

Biomass measurement is a prerequisite for tcarbon stock estimation and the calculation of CO_2 sequestration to the environment (Alimbon et al. 2021; Howard et al. 2014). Biomass estimation enables the comparison of productivity among forest ecosystems. The carbon stock (80.28 t ha^{-1}) and carbon sequestration (294.63 t ha^{-1}) were recorded higher for *A. alba* due to the larger trees as compared to the other species. Comparatively, the mangroves in Jor Bay store 697.45 tons of carbon per ha and can uptake 2559.63 CO_2 per ha in total (Zulhalifah et al. 2021). It is very clear that the carbon stock and its sequestration increase or decrease with the tree biomass. It is again in line with the statement that mangrove forests can store carbon four times higher than terrestrial forests (Zulhalifah et al. 2021) and can help to reduce the climate change impact by absorbing CO_2 from the atmosphere (Mcleod et al. 2011).

In conclusion, mangroves are among the most productive ecosystems in the world. The zonation pattern of mangroves in the Setiu lagoon was dominated by geographical and ecological factors, with discrete groupings in this lagoon's ecosystems. Mangrove species in the Setiu lagoon had high species diversity, species richness, and the ability to store carbon from the atmosphere, so they are making a good contribution to CO_2 reduction. The outcomes of this study could be a preliminary source of information and can provide baseline data for the ecological study of a lagoon ecosystem in the tropical climate.

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