Spatial distribution and dynamics of selected mangrove forests on the east and west coasts of Sri Lanka

Wasana de Silva[1]*, K.A. Roshan S. Perera[2], Mala D. Amarasinghe[1]

[1]*Department of Plant and Molecular Biology, Faculty of Science, University of Kelaniya 11600, Sri Lanka*
[2]*Department of Botany, Faculty of Science, The Open University of Sri Lanka, Nawala, Nugegoda 11222, Sri Lanka*

*Corresponding author: wasanaldes@gmail.com

ORCID ID: https://orcid.org/0000-0001-8206-9260

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Abstract The climate and edaphic characteristics primarily determine the spatial distribution and dynamics of mangrove forests. The present study was initiated to determine how species composition and structural characteristics vary along with climate and substrate salinity of six mangrove forests located on the west coast, i.e., Negombo estuary, Chilaw lagoon, and Malwathu oya estuary, and east coast, i.e., Batticaloa lagoon, Uppar lagoon, and Urani lagoon. The structural parameters in terms of tree height, basal area, biomass, and density were obtained to determine the vegetation structure of mangrove forests. The current study found that although the structure of mangrove communities of the two coasts does not differ significantly ($P<0.05$), plant diversity in mangrove areas on the west coast is significantly higher than that of the east coast mangroves. In contrast, the biomass accumulation in west coast mangroves is relatively lower than that of east coast. Tree height was found to influence the productivity in terms of biomass increment of mangrove forests under investigation. As such, our study suggests that regional variations in salinity, temperature, and rainfall primarily serve as drivers of variation in mangrove species composition and vegetation structure of mangrove forests along the coasts of Sri Lanka.

Keywords: mangroves, species composition, diversity, western and eastern coasts, geographical distribution, Sri Lanka

INTRODUCTION

The spatial distribution and vegetation structure of mangroves in different localities are influenced by many factors such as temperature, precipitation, freshwater runoff, erosion/sedimentation rates, aridity, salinity, nutrient inputs, and ocean circulation pattern (Gilman et al. 2008; Osland et al. 2017; De Silva and Amarasinghe, 2010; Record et al. 2013; de Silva and Amarasinghe 2021a). These factors may largely determine the floristic and faunistic composition and the community structure of the mangrove ecosystem (Cintron et al. 1985; Cintron and Novelli 1984).

The vegetation structure is the product of interactions between physical, chemical, biological, and anthropogenic factors that operate in an ecosystem for a considerable time. Furthermore, the vegetation structure of mangrove forests is influenced by different environmental factors that act on different scales of time and space and with different intensities and frequencies (Cintron and Novelli 1984). The structure and function of the mangroves reflect the cumulative nature and intensity of these external forces, and their action varies widely over geographical regions, and hence, mangrove stands exhibit wide regional and local variations structurally and floristically. Bhatta (2021) described that vegetation structure and species composition play a vital role in biodiversity. The species composition, diversity, stem height and diameter, basal area, canopy cover, and spatial distribution patterns (zonation) are the component species in the forest.

Limited in-depth studies are available on the vegetation structure of mangroves in specific areas of Sri Lanka i.e., Puttalam lagoon, Dutch Bay, and Kala Oya estuary (Amarasinghe and Balasubramaniam 1992; de Silva and de Silva 1989; Perera et al. 2013; De Silva and Amarasinghe 2021b), Chilaw lagoon, (Jayasuriya 1991; de Silva and Amarasinghe 2021a), Kalamatiya lagoon, Rekawa lagoon, and Galle, (de Silva and Amarasinghe 2021b; Jayatissa et al. 2002; Dahdouh-Guebas et al. 2002), Negombo estuary (Pahalawattaarchchi 1995; Jayakody et al. 2008) and Batticaloa lagoon (Rajeeshan and Jayasingam 2000).

Climatic drivers i.e., temperature and rainfall and edaphic characteristics, particularly substrate salinity, determine the species composition, vegetation structure and diversity of mangrove forests. Hence climate change brings alteration of the spatial distribution pattern of mangrove forests. Therefore, it is crucial to understand the local distribution pattern of the mangrove species to assist the sustainable mangrove management interventions on the island. Our study focuses on 1) determining regional-scale variations on mangroves in terms of vegetation structure, species composition, and diversity, 2) in-depth investigations of biomass retention capacities of mangrove ecosystems located on western and eastern coasts, and 3) the significant impact of substrate salinity, temperature, and rainfall on vegetation structure, diversity, and spatial distribution of mangroves on the island.

MATERIALS AND METHODS

Study areas

The current study was performed on the western and eastern coasts of Sri Lanka. The study sites were selected to represent different climatic zones, i.e., Negombo estuary in the wet zone (West coast - 7˚11′50 48" N; 79˚ 50′47.50" E), Chilaw lagoon in the intermediated zone (West coast -7°30′46.40" N; 79° 49′11.70"E), and Malwathu Oya estuary (West coast - 8°49' 02.64"N; 79° 55' 09.24" E), Uppar lagoon (East coast - 8° 05′ 13.25′′N; 81° 26′15.92 E), Batticaloa lagoon (East coast -7° 44′ 50.70" N; 81°41′17.67" E) and Urani lagoon (East coast) in the dry zone (Figure 1). Negombo estuary is a shallow water body, and its approximate extent is 3,502 ha. The mean annual temperature and mean annual precipitation at the lagoon area are 27.9 °C and 2161mm (IUCN Sri Lanka and the Central Environmental Authority 2006). The total extent of the Chilaw lagoon area is 1800 ha and the mangroves occur along the lagoon shoreline and in the islands (Jayasundera et al.1999). The mean annual temperature and mean annual precipitation of the lagoon area are 27.9 °C and 150.8 mm, respectively. Malwathu oya estuary extends over 89.45 km^2 on the northwest coast of Sri Lanka (Silva et al. 2005). This estuarine area receives 923.5 mm of precipitation annually, and the mean annual temperature is 29.3 °C. Batticaloa lagoon is rich in biodiversity, and mangroves are found around the lagoon. The lagoon extends over 2,590 ha (Perera and Amarasinghe 2021). The mean annual temperature and mean annual precipitation of the Batticaloa lagoon are 28.5 °C and 1786.4 mm, respectively. The maximum depth of the Urani lagoon is 2-3 m, and the Uppar lagoon extends approximately 2,590 ha, and the average depth is 1-2 m (Perera and Amarasinghe 2021). The reported annual temperature and precipitation of the lagoon area are 29.2 °C and 1810.4 mm, respectively for the study period from 2013 to 2016.

Sampling strategy to determine community structure

Belt transects of 10m width were laid perpendicular to the shoreline across the water-land ecotone in representative locations within each 6-study sites located on the west and east coasts of the island. Each transect was divided into 10m x 10m sampling plots, and a total of 115 sampling plots were used to collect data from the 6 study areas. All mangrove trees encountered in the study plots were identified and enumerated.

Vegetation structural parameters

The linear vertical distance between the ground and the tip of the tree crown was recorded using an altimeter for tall trees and a calibrated pole (at 0.25 m intervals) to measure height of short trees. The method described by Jayakody et al. (2008) and Kathiresan and Khan (2010) were used to measure leaf area index (LAI), i.e., measurement of photosynthetically active radiation (PAR) absorbed by the canopy to estimate the leaf area index. The light intensity of the above canopy or in the open space of the study area and under the canopy was recorded between 10.00 a.m. and 2.00 p.m. using LI-191SA line Quantum sensor. Approximately 50 readings were taken from each study plot, and accordingly, more than 1000 readings were obtained from each area. Species diversity of all the plants encountered in the study site with diameters above 2.5 cm were considered to calculate the Shannon-Wiener diversity index (H′). The complexity index (CI) of flora within the forest community was calculated using equation 1 (Holdridge et al. 1971; Jayakody et al., 2008; Kathiresan and Khan 2010).

CI = Number of species x stand density x stand basal area x stand height x 10^{-5} …………… (1)

In the present study, the allometric relationships were used to estimate the above-ground and below-ground biomass of mangrove species (Table 1).

Table 1 Allometric equations used to determine the above and below-ground biomass of mangroves in the present study.

Mangrove species	Above-ground biomass (AGB)	Below-ground biomass (BGB)
Bruguiera gymnorrhiza	AGB= 0.289 $(dbh)^{2.327}$ (Perera et al. 2012)	BGB= 0.100 $(dbh)^{2.364}$ (Perera et al. 2012)
Lumnitzera racemosa	AGB= 0.114 $(dbh)^{2.523}$ (Perera et al., 2012)	BGB= 0.118 $(dbh)^{2.063}$ (Perera et al. 2012)
Rhizophora mucronata	$\log_e$(AGB)= 6.247+2.64 $\log_e$(dbh) (Amarasinghe and Balasubramaniam 1992)	
Avicennia marina	$\log_e$(AGB)= 5.551+2.153$\log_e$(dbh) (Amarasinghe and Balasubramaniam 1992)	
Rhizophora apiculata		
Bruguiera cylindrica		
Excoecaria agallocha		
Ceriops tagal		
Aegiceras corniculatum	AGB= 0.251 ρ dbh $^{2.46}$	BGB= 0.199 ρ $^{0.899}$ dbh $^{2.46}$
Avicennia officinalis	(Komiyama et al. 2005)	(Komiyama et al. 2005)
Sonneratia alba		
Pemphis acidula		
Xylicarpus granatum		

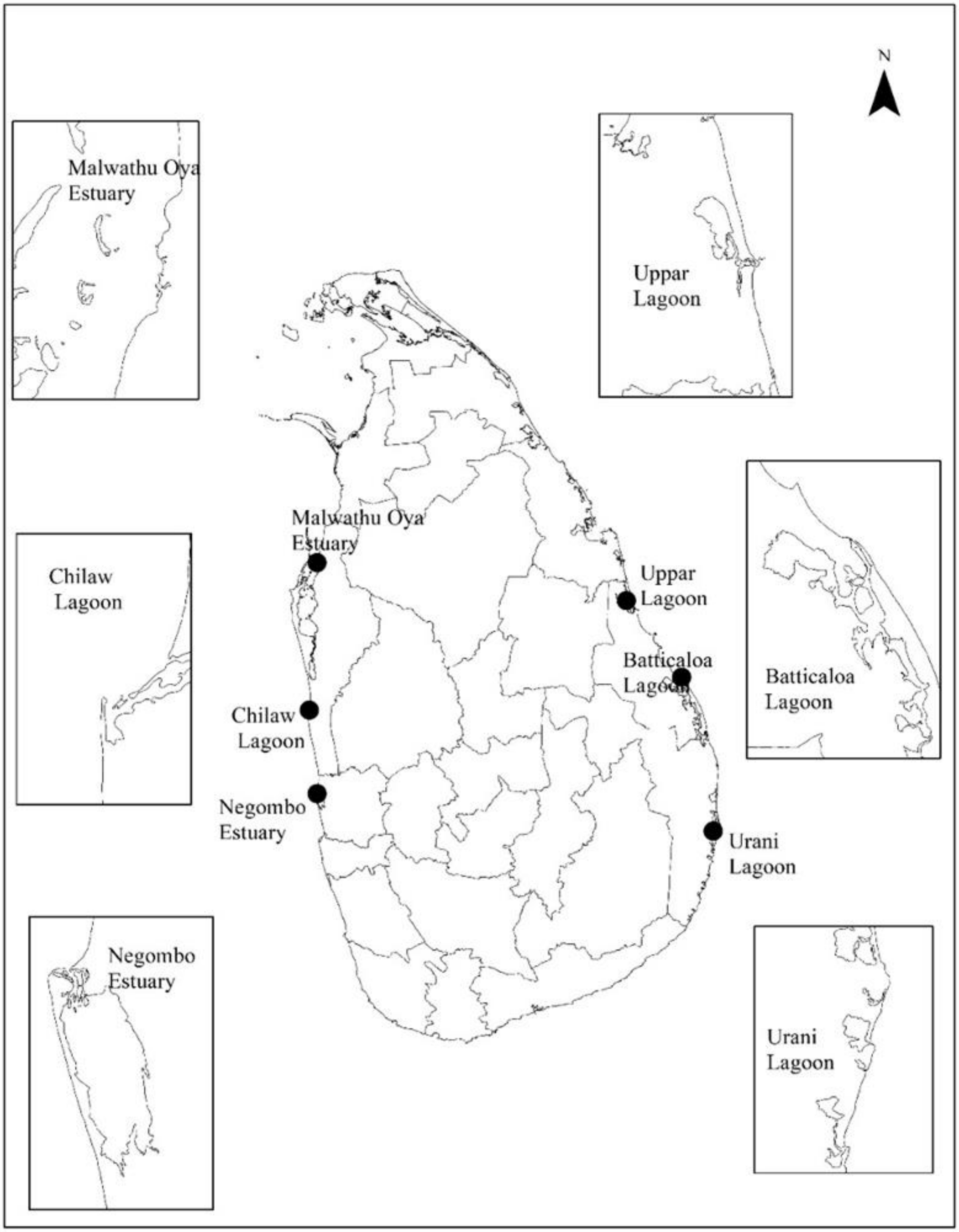

Fig 1 Study site of the mangrove areas on west and east coasts of Sri Lanka

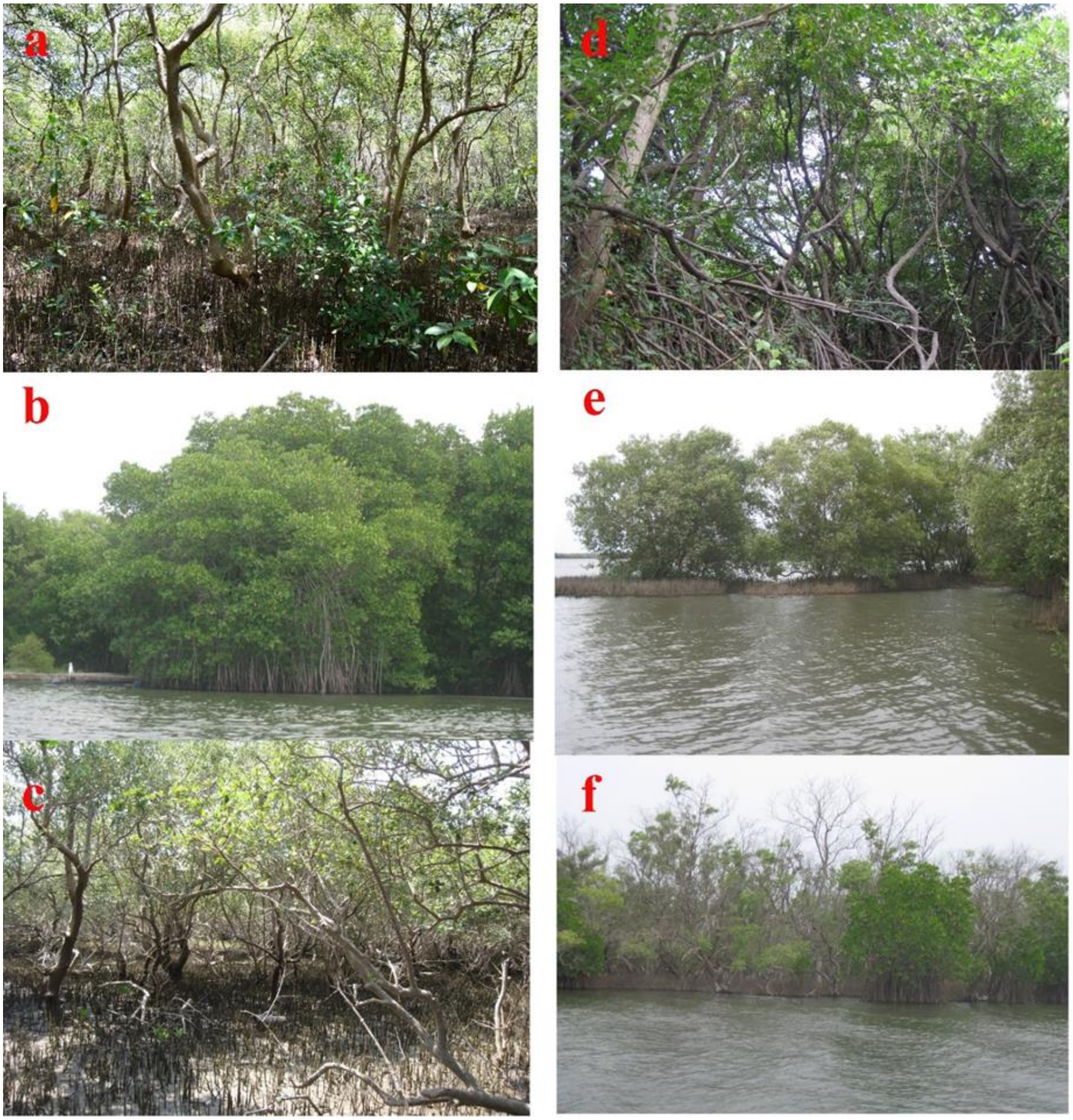

Fig 2 Mangrove study sites on western and eastern coasts of Sri Lanka a) Negombo estuary, b) Chilaw lagoon, c) Malwathu Oya estuary, d) Batticaloa lagoon, e) Uppar lagoon, and f) Urani lagoon

Table 2 Mangrove species encountered at the study sites on East coast and West coast, Sri Lanka.

Mangrove Species	West coast			East coast		
	Negomb oestuary	Chilaw lagoon	Malwathu Oya estuary	Batticaloa lagoon	Uppar lagoon	Urani lagoon
Rhizophora mucronata	+	+	+	-	+	+
Rhizophora apiculata	+	+	+	+	+	-
Bruguiera gymnorrhiza	+	+	-	-	-	+
Bruguiera cylindrica	+	-	-	-	-	-
Bruguiera sexangula	+	+	-	-	-	-
Avicennia marina	+	+	+	+	+	-
Avicennia officinalis	-	+	-	+	-	-
Lumnitzera racemosa	+	+	-	-	+	-
Excoecaria agallocha	+	+	+	+	+	+
Ceriops tagal	+	-	-	-	-	-
Aegiceras corniculatum	+	+	-	-	-	-
Sonneratia alba	-	-	+	-	-	-
Pemphis acidula	-	-	+	-	-	-
Xylocarpus granatum	-	+	-	-	-	-
Acanthus illcifolius	+	+	+	+	+	-

"+" sign shows present of the species and "-" show the absent of the species

Collection of soil salinity and weather data

The salinity of mangrove soil was recorded from each study transect along the gradient. Soil salinity of interstitial water was obtained by pressing soil with a plastic syringe and was measured with a portable refractometer (iuchi IS-Mill-E). Mean salinity was calculated with salinity measurements made at four randomly selected localities in each 10 m x 10 m sub-plot. The mean annual temperature and mean annual precipitation of each study site were collected from the Meteorological Department.

Statistical analysis

Mangrove vegetation structure was analyzed and presented as Complexity index (CI) and diversity index. Correlation analysis was performed to investigate the association between environmental parameters and vegetation structural parameters (R Development Core Team 2020). Alpha-diversity at each study site was calculated with the R package vegan (Oksanen 2019). Furthermore, a paired-sample t-test was performed to compare vegetation structural parameters of mangrove forests on the west and east coasts.

RESULTS

In the current study, a total of thirteen mangrove species were encountered in the study sites, of which eleven species were presented in the Negombo estuary and Chilaw lagoon. A total of seven mangrove species were enumerated in the sampling plots at Malwathu Oya estuary. Relatively a few mangrove species (5 – 6 species) were encountered in the sampling plots at Batticaloa and Uppar lagoons. As such, species richness in mangrove areas on the west was significantly greater than that on the east coast. A list of the enumerated mangrove species of the sampling plots is presented in Table 2

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On average, the taller trees occur in mangrove areas of Urani lagoon (6.94±0.21 m), followed by Batticaloa lagoon (6.63±0.11 m), Chilaw lagoon (5.42± 0.8m), Uppar lagoon (5.34±0.07 m). Moreover, *R. mucronata* (10 m) was the tallest among mangrove trees found at Urani lagoon, while *Rhizophora apiculata* (13 m) was the tallest at Batticaloa lagoon and *L. racemosa* (12 m) at Chilaw lagoon (Figure 3). Under the studied mangrove areas, the highest basal area was obtained from Negombo estuary (159.98±21.69 m^2), whereas the lowest was obtained from Chilaw lagoon (16.36±12.93 m^2). Leaf area index (LAI) of mangrove areas ranged between 5.38 to 7.31 m^2 ha^{-1}. The highest values of LAI were recorded from the Negombo estuary on the west coast (Figure 4). Our results show mangrove diversity on the west coast is higher when compared to the diversity of the east coast. Figure 5 depicts the maximum and the minimum diversities obtained from the mangrove areas on the west coast, suggesting the diversity distribution of species on the west coast mangrove areas is comparatively high when compared to the diversity on the east coast. The Urani lagoon records the highest above ground and below-ground biomass, i.e., 449.81±0.25 Mg ha^{-1} for above-ground biomass and 94.62±0.05 Mg ha^{-1} for below-ground biomass. However, the lowest above-ground and below-ground biomasses were recorded from Chilaw lagoon located on the west coast, i.e., 140.13±0.02 Mg ha^{-1} for above-ground biomass and 46.13 ±0.01 Mg ha^{-1} for below-ground biomass (Figure 6).

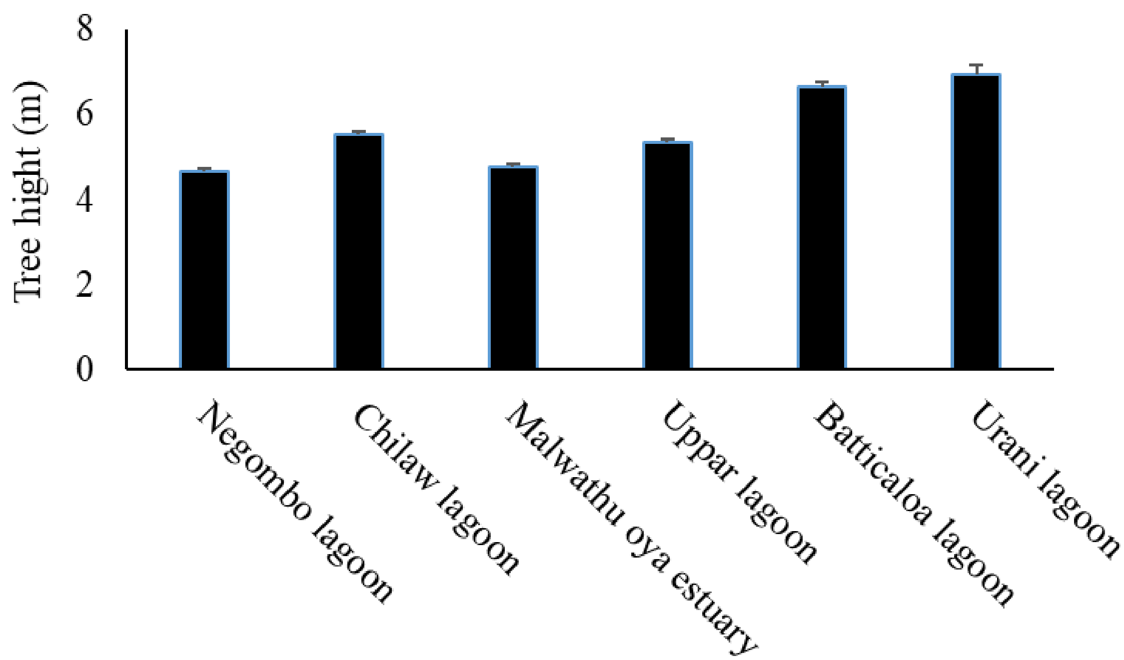

Fig 3 Average tree height of the study sites. The error bars indicate the standard error of the mean tree height of the study sites

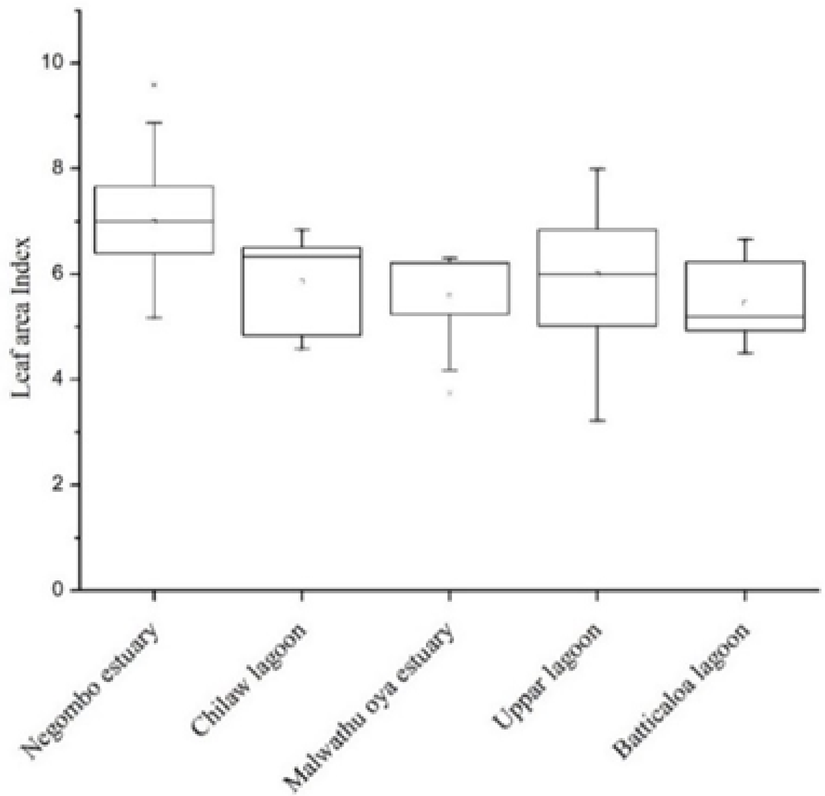

Fig 4 The standard boxplots depict the distribution of leaf area index across the six study sites. Boxes represent the upper quartile, lowest quartile, and median. The upper and lower whiskers of the diagram represent the highest and lowest observations.

The highest stand density, 4325 stems ha^{-1} was recorded at the Batticaloa lagoon, and the Chilaw lagoon recorded the second highest stand density, i.e., 3976 stems $ha^{-1.}$ In contrast, Urani lagoon and Malwathu Oya recorded the lowest values, i.e., 1100 stems ha^{-1} for Urani lagoon (Table 3). According to our study, relatively high stand densities were observed in the estuarine waterfront, declining towards the inland.

Diversity is significantly higher on the west coast mangrove areas when compared to the east coast, and diversity varies considerably on the west coast of the island (Figure 5). The correlation matrix describes a strong negative correlation between salinity and tree height (r = -0.76) followed by salinity and density (r = -0.54), whereas a strong positive correlation between salinity and diversity (r = 0.83). Furthermore, our results show that the basal area has a positive correlation (r = 0.66) with rainfall whereas a negative correlation with temperature (r =-0.54) (Figure 5). However, the paired sample t-test indicated no statistically significant difference between (P <0.05) vegetation structural parameters in terms of diversity, height, biomass, and density on the mangrove forests of the east and west coasts of Sri Lanka.

Table 3 Stand structural complexity of the study sites on the west and east coasts

Coastal zone	Study site	Density (Stem ha^{-1})	Number of species	Height (m)	Basal area (m^2)	Complexity Index
West coast	Negombo estuary	3555	10	4.67	159.99	265.55
	Chilaw lagoon	3976	9	5.52	16.364	32.31
	Malwathu Oya estuary	2700	6	4.74	19.14	14.71
East coast	Batticaloa lagoon	4325	3	6.63	30.79	26.51
	Uppar lagoon	3548	5	5.33	20.76	19.65
	Urani lagoon	1100	4	6.94	0.0038	0.00192

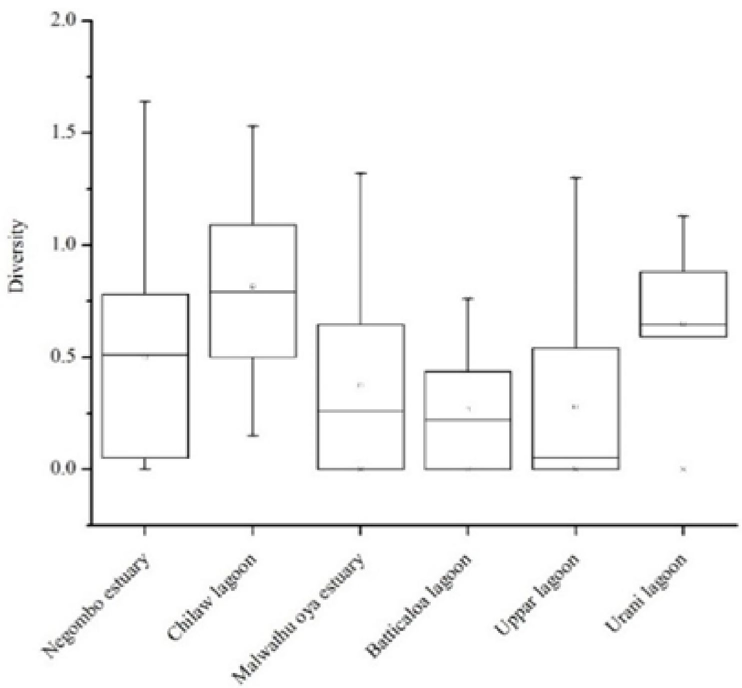

Fig 5 The standard boxplots depict species diversity distribution across the six-study site. Boxes represent the upper quartile, lowest quartile, and median. Upper and lower whiskers of the diagram and represent the highest and lowest observations.

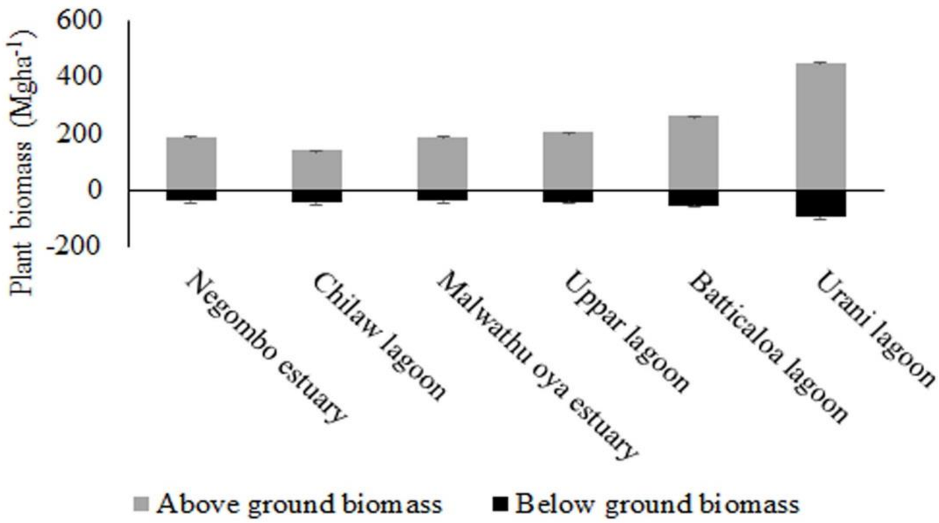

Fig 6 Biomass mangrove plants found at the study sites. The error bars indicate the standard error of the biomass of trees of the study sites

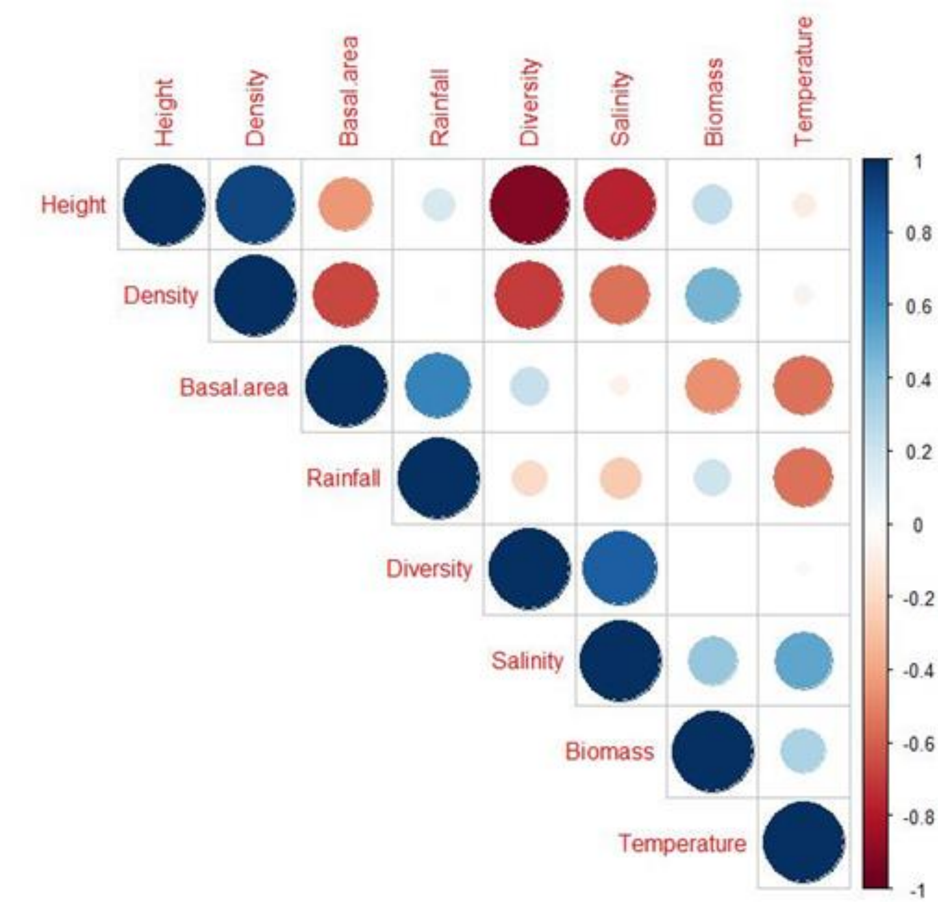

Fig 7 The correlation matrix applied for structural and environmental parameters of the study sites. Values in the vertical axis are Pearson correlation coefficients

DISCUSSION

Vegetation structure that depends on the species composition, diversity, basal area and tree height of mangrove vegetation determines the functional capacity of an ecosystem. This information therefore is important to assess the ecological and conservation status that indicate the goals of appropriate management strategies for respective mangrove ecosystems. Spatial distribution of mangrove species across the island revealed that a few species, i.e., *Rhizophora mucronata, R. apiculata, Avicennia marina, Lumnitzera racemosa*, and *Excoecaria agallocha* are the most common species both on the western and eastern coasts. Similar observations have been reported by Amarasinghe and Balasubramaniam (1992) and Jayatissa et al. (2002) through studies conducted in mangrove ecosystems on the north-western and southern coasts of Sri Lanka.

Mangrove species are with varying capacities of coping with soil salinity, and they thrive under optimum saline conditions. *A. marina* and *R. mucronata* were found to survive in a wide range of soil salinity (de Silva and Amarasighe 2021a) and it influences the natural distribution of mangrove species (Ball 1998, Barik et al. 2017, De Silva and Amarasinghe 2021a). Results of the current study corroborate this observation, i.e. mangrove species composition and diversity are manifestations of the salinity regime of a habitat.

R. apiculata thrives in soils of very low salinity (de Silva and Amarasinghe 2010, 2021a) such as in Batticaloa lagoon (mean salinity is 12 ppt), Chilaw lagoon (mean salinity is 18 ppt), and Negombo estuary (mean salinity is 18 ppt). Besides, our study revealed that salinity of the substrate influences plant biomass or the standing stock of mangrove vegetation, manifesting the effect of salinity on mangrove plant growth and net primary productivity. Increased soil salinity elevates salt content in mangrove plant tissues that decreases water availability causing a decline in productivity (Lovelock et al. 2006; Gilman et al. 2008; Osland et al. 2014; de Silva and Amarasinghe 2021a). As such, our results suggest that local changes in salinity influence the species composition and hence the spatial distribution of mangroves across the island. Soil salinity however, may not be the only factor that affects species distribution and plant diversity of mangrove ecosystems. Tidal currents often regulate mangrove seed/seedling dispersal and distribution in coastal waters. Besides, availability of nutrients in the substrate also determines the types of plants that survive and perform well (Amarasinghe and Perera, 2017, Cintron et al, 1985).

Different climatic factors have impacted the mangrove communities, and fluctuations in local climate profoundly affect mangrove vegetation (Barik et al. 2017). Rainfall plays an essential role in mangrove forests (Osland et al. 2017). Findings of the present study substantiate this observation as growth performance in terms of tree height, basal area, and biomass showed significant correlations with rainfall and temperature. Rains increase nutrient availability particularly in estuaries and contributes to maintain more favourable edaphic conditions for enhanced nutrient uptake by plants thus, affecting the productivity of mangroves (Record et al. 2013). The western and eastern coasts of Sri Lanka experience variations of rainfall. The study showed that rainfall has a significant association with species distribution and vegetation structure of mangrove forests on the western and eastern coasts of Sri Lanka. Mangroves thrive in high rainfall and warm areas (Snedaker 1995) and our results substantiate this observation, as the biomass of mangrove species considered in this study showed a positive correlation with rainfall. Plant biomass however showed a negative association with the basal area (Figure 7), suggesting biomass increment of the mangrove forests is influenced by tree height and density of the mangrove vegetation. Declining rainfall and increasing evapo-transpiration increases soil salinity. Therefore, reduced rainfall decreases productivity in terms of biomass increment, causing a notable reduction in mangrove plant growth and development. Furthermore, our study reveals that the vegetation structure in terms of tree height, basal area, and biomass on the east coast are higher than that on the west coast.' while mangrove plant diversity is higher on the west coast than that on the east coast, resulting similar structural diversity complexity values. Apart from differences in coastal erosion/ accretion status (Lowry and Wickremeratne 1988; de Silva and Amarasinghe 2021b) and the anthropogenic pressure on the two coastal areas (de Silva and Amarasinghe 2021a). dispersal of mangrove seeds/ seedlings

(Amarasinghe and Perera 2017) may have contributed to the variation in mangrove species diversity of the two coasts. Atmospheric temperature and its' fluctuations influence the distribution, diversity, and abundance of mangroves (Osland et al. 2017) by affecting phenological pattern, and productivity of mangroves. Rising temperature increases productivity when it does not exceed an upper threshold (Gilman et al. 2008). Our results too revealed a positive correlation between temperature and plant biomass. The negative correlation between temperature and basal area however, suggests that regional variation of temperature influences mangrove net primary productivity.

Disclosure statement

The author declares that they have no competing interests.

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