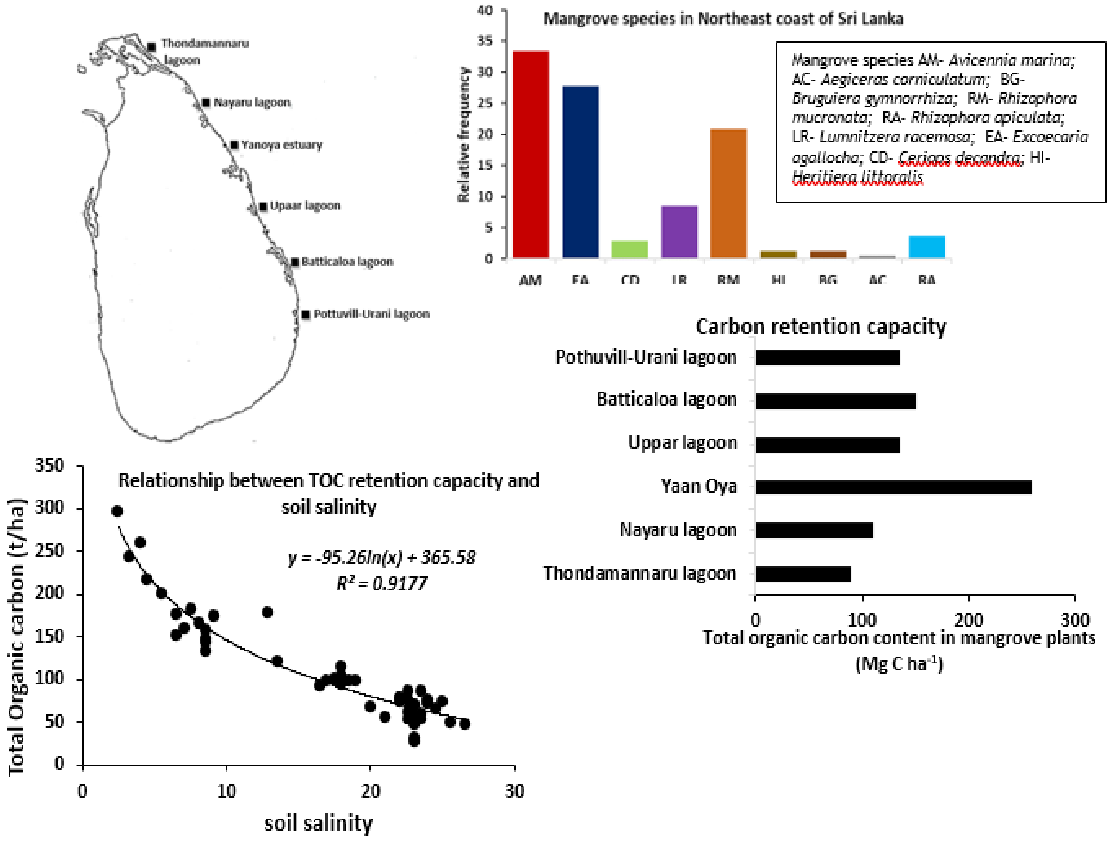
RESEARCH ARTICLE

Vegetation structure, biomass and carbon retention capacity of mangroves at Northeast coast of Sri Lanka

K.A.R.S. Perera* and M.D. Amarasinghe*



Highlights

- Highest mangrove diversity was at Yan Oya followed by Thondamannaru and Uppar lagoons.
- A critically endangered mangrove species, *Ceriops decandra* was recorded at Yan Oya.
- Relatively higher biomass values (159-460 Mg ha^{-1}) recorded at Yan Oya estuary.
- Average above ground biomass of the northeast coast of Sri Lanka was 226.34 Mg ha^{-1}.
- Relationship was revealed between soil salinity and TOC retention in mangroves.

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RESEARCH ARTICLE

Vegetation structure, biomass and carbon retention capacity of mangroves at Northeast coast of Sri Lanka

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Abstract: Mangroves represent one among the most carbon retaining ecosystems in the world, due to their high productivity and huge carbon sinking capacity within biomass and substratum. Majority of Sri Lankan mangroves are located on the north-eastern coast. Since they were highly isolated during the last three decades, there are limited research publications related to those. Present study was conducted at six major mangrove ecosystems in the northeast coast of Sri Lanka with the objectives of reporting the present vegetation structure and to estimate their capacity of the carbon pool with plant biomass. Highest mangrove diversity was recorded at Yanoya followed by Thondamannaru and Uppar lagoons. A critically endangered mangrove species, *Ceriops decandra*, was recorded at Yanoya mangrove ecosystem, this may be the first-time scientific record of the species in the recent history. Relatively higher biomass values (159 - 460 Mg ha^{-1}), recorded at Yanoya estuary. The average value for above ground biomass of the northeast coast of Sri Lanka was 226.34 Mg ha^{-1}. Statistically significant linear relationships occurred between the biomass and the mangrove vegetation structure, as well as between the soil salinity and the carbon retention capacity of mangrove. Results of the present study assist to add new knowledge and rationalize the conservation and proper management of mangrove ecosystems on the northeast coast of Sri Lanka.

Keywords: Vegetation structure; biomass; carbon retention capacity; mangroves.

INTRODUCTION

Mangrove forests are critical inhabitants of the border line between land and the sea, being key ecosystems in many tropical and subtropical coastlines of the world. They are true ecotones, being not just transitional in nature, containing some elements of terrestrial as well as marine ecosystems. Mangroves exist in conditions of high salinity, inundations by tides, strong winds, high temperatures with direct sunlight and anaerobic muddy soils. They have suitable adaptations for all these stresses and no other group of flowering plants with such highly developed morphological and physiological adaptations to such extreme conditions (Kathiresan *et al*., 2015).

Mangroves are important with their ecological, economic, and social values and services (Saenger, 2002; Lacambra *et al*., 2013;). In addition to common economical and social services, recent research revealed that mangroves are one among the world's most productive ecosystems, assimilating organic carbon well in excess of the ecosystem requirements and substantially contributing to the global carbon cycle (Kathiresan *et al.,* 2015). The carbon sequestration capacity of this highly productive ecosystem is a function of biomass accumulation. It was proved that interactions between physical, chemical, climatic and topographic elements depends on the accumulation of plant biomass (Kirui *et al*., 2006).

Total estimates on the global extent of mangroves nearly 17 million ha (Aizpuru *et al*., 2000) distributed among 121 countries in the world (Spalding *et al*., 1997). The precise number of species is still under debate and recorded range from 50 to 70, according to different classifications (Lugo and Snedaker, 1975; Saenger, *et al*., 1983; Tomlinson, 1986; Aksornkoae*et al.*, 1992), and Asian region followed by the eastern Africa recorded the highest diversity of mangroves.

Due to the geographical location of Sri Lanka, overall climate of the island characterized as tropical and recorded high biodiversity mangrove areas comprised of twenty-five (25) true mangrove species and thirty-four (34) mangrove associated plant species (Amarasinghe and Perera, 2017). Based on the prevailing annual rainfall, three main climatic zones, wet, intermediate and dry zone are identified. The climatic pattern of Sri Lanka is mainly determined by the creation of monsoonal wind patterns in the surrounding oceans. The coastline of Sri Lanka is approximately 1338 km long (Silva *et al*., 2013) and more than 70% of coastline is located in the dry climatic zone where receiving of annual rainfall is less than 1750 mm. Current extent of mangroves in Sri Lanka recorded as 15,670 ha, interspersing of 13 administrative districts along the coastline of the country (Edirisinghe *et al*., 2012; Prasanna *et al*., 2019). Based on the distribution of mangroves in Sri Lanka, majority are located on the northern and eastern coasts. Total of 10,515 ha, which represent the 67% of the total mangrove extent is restricted to northern and eastern coasts. District wise breakdown of mangrove extent was reported as, 618 ha at Ampara, 2,071 ha at Batticaloa, 2,505 ha at Jaffna, 1,885 ha at Kilinochchi, 1,041 ha at Mullaitivu, and 2,395 ha at

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Trincomalee (Edirisinghe *et al.,* 2012). These areas were highly isolated during last thirty years due to the war situation of the country and limited research data were available on coastal ecosystems of such areas. Therefore, the present study was conducted with the objectives of reporting the present vegetation structure and estimating their capacity of carbon pool with plant biomass at six major mangrove ecosystems, Thondamannaru lagoon, Nayaru lagoon, Yanoya estuary, Batticaloa lagoon, Uppar lagoons and Pottuvill-Urani lagoon, found along the north east coast of Sri Lanka.

MATERIALS AND METHODS

Study areas

Study was conducted in six (06) mangrove areas along the northern, northeastern and eastern coastal zones of Sri Lanka. Coastal zones were classified according to Silva *et al.,* (2013). Thondamannaru lagoon, Nayaru lagoon and Yanoya estuary were selected to represent the Northern coastal zone, Batticaloa, Uppar lagoons were selected to represent the Northeastern coastal zone and Pottuvill-Urani lagoon was selected to represent the Eastern coast of Sri Lanka (Figure 1 and Table 1). All six selected study areas are located in the dry climatic zone of Sri Lanka. Thondamannaru lagoon is in the interior of the Jaffna Peninsula and east of Jaffna District, Northern Province. Total lagoon area is recorded 7,787 ha. A shallow (about 2 m depth) lagoon stretching for about 45 km along and at the northwestern section it is connected to the Indian Ocean by a narrow channel (Kotagama, *et. al*., 1989; Silva *et. al*., 2013). Nayaru lagoon (some reference indicates as "Nai Aru" Lagoon), located in Mullaitivu District, Northern Province and the total area is 1,760 ha. The maximum depth was recorded about 3-4 m at the mouth of the lagoon (Kotagama, *et al*., 1989). The freshwater inflows through irrigation streams and the regular sandbars create barriers

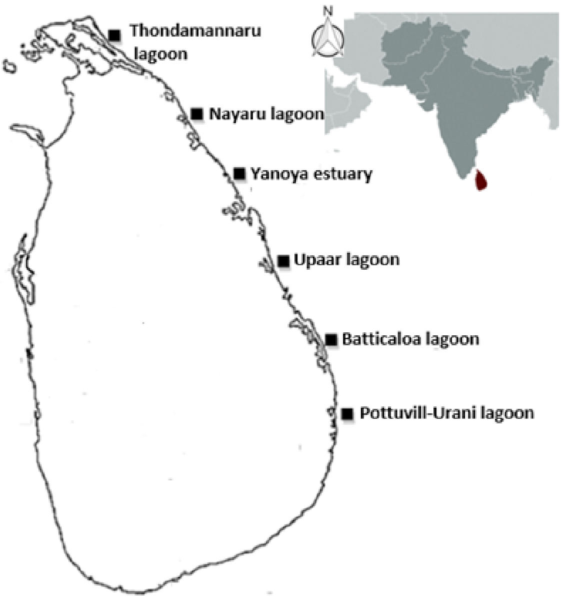

Figure 1: Locations of study areas.

to the sea. Yanoya estuary is located in Trincomalee District, Eastern Province of Sri Lanka. Estuary created with the Yanoya, the fifth-longest river (approximately 142 km) of Sri Lanka. Its catchment area, 1,520 km^2 receives approximately 2,371 million m^3 of fresh water per year. Maximum depth of about two meters (Kotagama, *et al*., 1989; Silva *et al*., 2013).

Upaar (Panichchankeni) lagoon is located in Batticaloa District, Eastern Province and lagoon area recorded around 2,590 ha. Average depth of the lagoon recorded 1-2 m and fed by number of small streams. Lagoon opens to the sea through a narrow channel at its southern end (Kotagama, *et al*., 1989; IUCN Sri Lanka and the Central Environmental Authority, 2006; Silva *et al*., 2013).

Batticaloa lagoon is located in the east coast at Batticaloa District. This is relatively large (14,118 ha.) and a deep lagoon (about 4 m) which connects to the sea with two narrow channels (IUCN Sri Lanka and the Central Environmental Authority, 2006; Harris and Vinobaba, 2013). Sand bars are created by high wave action occur during the dry season, which blocks the connections to the sea. The lagoon receives fresh water from several small canals during the rainy season.

Pottuvill-Urani lagoon is located in the Ampara District, of the Eastern Province of Sri Lanka. The lagoon is connecting with the Indian Ocean by a channel found on its eastern part. There are a number of small streams joining to the lagoon with freshwater inputs. Maximum depth of the lagoon is 2-3 m, while salinity levels change seasonally and can be over 30 ppt (Kotagama, *et al*., 1989; IUCN Sri Lanka and the Central Environmental Authority, 2006; Silva *et al*., 2013).

Sampling strategy

Strata were identified along the obvious environmental gradient from estuarine shoreline and banks of the creeks towards the inland. In order to collect data on vegetation structure, 10 m wide belt transects were laid perpendicular to the estuarine/lagoon shoreline across the environmental gradient in randomly selected points in each study area. Two to six numbers of transects were laid in each study area. Each transect was divided into 10 m × 10 m sampling plots and a total of sixty-eight (68) sampling plots were laid in all six study areas. All mangrove trees only the stem girth greater than 2.5 cm encountered. Trees in the study plots were identified, numbered and mapped. Girth diameter at breast height (dbh) and tree height were measured using accepted methods described by Cintron and Novelli (1984), and Kathiresan and Khan (2010) from each laid study plot (100 m^2) at all study areas.

Basal area, stand density, stand height, mean stand diameter and complexity of index (CI) of constituent species was calculated with standard methods (Cintron and Novelli, 1984; Kathiresan and Khan, 2010; Perera and Amarasinghe, 2016).

Soil salinity

Salinity of mangrove soil was recorded for at least one transect (along the gradient) of each study area. Each

Table 1: Study locations and their climatic characteristics

Study area	location	Annual rainfall (mm)[a]	Relative humidity (%)[a]	Annual temperature (^{0}C)[a]
Thondamannaru lagoon	9^0 42'07.28" N; 80^0 17'02.80 E	1033.3	83 - 91	25.3 - 30.2
Nayaru lagoon	9^0 07' 42.27" N; 80^0 51'49.19 E	1492.5	78 - 90	25.8 - 30.2
Yanoya estuary	8^0 53' 51.47" N; 81^0 00'00.25 E	1492.5	78 - 90	25.8 - 30.2
Uppar lagoon	8^0 05' 13.25" N; 81^0 26'15.92 E	1973.7	76 - 88	25.8 - 30.5
Batticaloa lagoon	7^0 44' 50.70" N; $81^0$41'17.67 E	1973.7	76 - 88	25.8 - 30.5
Pottuvill-Urani lagoon	$6^0$55' 11.98" N; 81^0 50'17.29 E	1613.0	80 - 92	26.0 - 29.9

[a]*Source: Bastiaanssen and Chandrapala (2003*).

Table 2: Summary of allometric relationships/ equations used to determine the above and below ground biomass of mangrove plants present in the study areas

Mangrove species	Allometric relationships used for determination of above ground biomass (AGB)	Allometric relationships used for determination 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)	$BGB = 0.199\ \rho^{0.899}\ dbh^{2.46}$ (Komiyama *et al*., 2005)
Rhizophora apiculata *Excoecaria agallocha* *Ceriops decandra* *Aegiceras corniculatum* *Heritiera littoralis*	$AGB = 0.251\ \rho\ dbh^{2.46}$ (Komiyama *et al*., 2005)	

soil sample was collected from the surface soil layer up to 5 cm depth and water was obtained by pressing of soil samples with a plastic syringe to obtain interstitial water and its salinity was recorded with a potable refractometer (iuchi IS-Mill-E) in the field. Mean salinity of the study plot was calculated with salinity measurements made at four randomly selected points in each study plot at selected transect.

Leaf area index

Differences between photon flux density recorded underneath of the mangrove canopy and top of the canopy/ open area was used to calculate the Leaf area index (LAI). By using LI-COR Terrestrial radiation sensor measured the photon flux densities, following the method described by Jayakody *et al.* (2008) and Kathiresan and Khan (2010). Gathering of solar radiation data in this study was restricted only to two study areas, Batticaloa and Uppar lagoon mangrove ecosystems.

Determination of biomass and total organic carbon (TOC) in mangrove plants

Allometric relationships developed for individual species as well as common equations were used to determine the above ground and below ground (root) biomass of mangrove plants encountered in study plots of all (06) study areas. Summary of the allometric relationships used to calculate the biomass values were presented in Table 2.

RESULTS

Mangrove vegetation structure

Total of nine (9) true mangrove species were encountered in the study plots of all six study areas and eight (8) species each were presented in Yanoya estuary. Relatively a lesser number of true mangrove species (2 - 3) were recorded in the sampling plots at Nayaru, Batticaloa and Uppar lagoons. In addition to that, few of true mangroves were observed in outside areas of the laid study plots of Thondamannaru lagoon. Those species are *Ceriops tagal* and *Heritiera littoralis.* Summary of the enumerated true mangrove species inside the sampling plots were presented in Table 2. Highest stand density was recorded at Nayaru lagoon (4,433 stems per ha), followed by Batticaloa lagoon (4,316 stems per ha) and Uppar lagoon (3,518 stems per ha). Highest mean dbh and tree height values were recorded at Batticaloa and Pottuvill-Urani lagoons, revealed that relatively large trees occurring in this area than other study areas in North-East coast of Sri Lanka. Species diversity of each study area was calculated with Shannon-Wiener index and highest diversity was at Yanoya estuary and followed by Thondamannaru and Uppar lagoons. Batticaloa mangroves recorded the highest values for complexity index (Table 3).

Above and below ground plant biomass at each sampling plot were calculated by allometric method and mean values were presented for each study areas. Biomass values were converted to the total organic carbon (TOC) contents with percentage TOC values for biomass of each mangrove species (Perera and Amarasinghe, 2016). Above and below ground highest biomass as well as TOC values were recorded at Yanoya estuary, followed by Batticaloa and Uppar lagoon mangroves (Table 4).

Species wise TOC content at different study areas was calculated. Percentage contribution of each mangrove species for the total TOC retention capacity of the study area was determined. All study areas, except Batticaloa and Pottuvill-Urani Lagoon, *Avicennia marina* was the highest contributing species for the TOC retention (Table 5).

A statistically significant ($p<0.05$) positive linear relationship was revealed to occur between vegetation structural complexity (CI) and total biomass of mangroves (Figure 2).

Table 3: Mangrove community structural variables recorded at six study areas

Study area	Species relative frequency	Stand density (per ha)	Mean dbh (cm)	Mean height (m)	Leaf area index	Species diversity	Complexity index
Thondamannaru lagoon	AM (50%); RM (15%); LR (26%) ; EA (9%);	2033	8.86 (5.9 – 16.1)	4.84 (1.5 -7.0)	**	0.94	3.20
Nayaru lagoon	AM (54%); RM (46%)	4433	8.68 (8.5 – 8.7)	4.48 (3.5 - 10.5)	**	0.68	12.61
Yanoya estuary	AM (28%); EA (26%); CD (17%); LR (9%); RM (7%); HI (7%); BG (3%); AC (3%)	2333	9.5 (3.6 – 19.6)	4.88 (1.5 – 13.0)	**	1.80	24.91
Uppar lagoon	AM (65%); RM (18%); LR (16%); EA (1%)	3518	6.83 (4.6 – 7.9)	5.55 (3.6 – 8.0)	5.47 ± 0.24	0.93	17.50
Batticaloa lagoon	EA (74%); RA (22%); AM (4%)	4316	10.71 (7.4 – 13.4)	6.79 (4.8 – 10.8)	5.39 ± 0.21	0.68	25.90
Pottuvill-Urani Lagoon	EA (57%); RM (39%); BG (4%)	1683	10.67 (8.8 – 11.7)	6.94 (3.0 – 12.0)	**	0.81	8.94

AM - *Avicennia marina;* AC - *Aegiceras corniculatum;* BG - *Bruguiera gymnorrhiza;* RM - *Rhizophora mucronata;* RA - *Rhizophora apiculata;* LR - *Lumnitzera racemosa;* EA - *Excoecaria agallocha;* CD - *Ceriops decandra;* HI - *Heritiera littoralis*
** - Data not available

Table 4: Mean biomass and total organic (TOC) carbon content in above and below ground components of mangrove plants at six study areas

Study area	Biomass (Mg ha^{-1})		Total organic carbon(Mg C ha^{-1})	
	Above ground	Below ground	Above ground	Below ground
Thondamannaru lagoon	131.78 ± 12.40	27.75 ± 2.61	74.19 ± 6.23	15.18 ± 1.62
Nayaru lagoon	189.51 ± 8.91	40.07 ± 3.59	91.07 ± 4.63	19.15 ± 1.73
Yanoya estuary	386.69 ± 7.33	74.30 ± 1.39	217.71 ± 4.12	40.64 ± 0.76
Uppar lagoon	212.30 ± 6.07	43.63 ± 1.03	112.59 ± 3.19	22.59 ± 0.53
Batticaloa lagoon	235.85 ± 8.46	49.87 ± 1.77	124.31 ± 4.85	25.38 ± 0.98
Pottuvill-Urani Lagoon	201.96 ± 2.65	51.14 ± 0.50	113.71 ± 1.06	22.16 ± 0.30

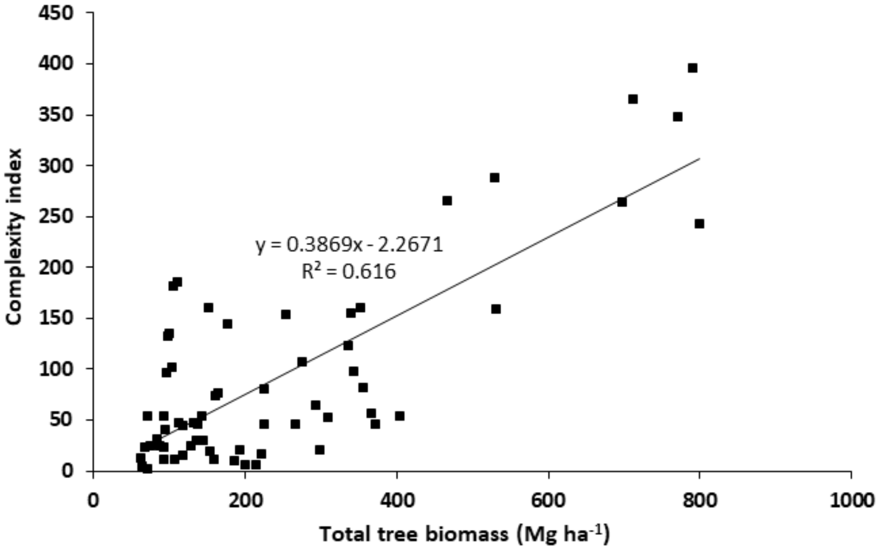

Figure 2: Relationship between vegetation structural complexity (CI) total biomass of mangroves.

Table 5: Species vise contribution to the maintaining of total organic carbon (TOC) stock in the vegetation of mangrove ecosystem at each study area

Mangrove species	Total (above and below ground) organic carbon content (Mg C ha^{-1})					
	Thondaimannaru lagoon	**Nayaru lagoon**	**Yanoya estuary**	**Uppar lagoon**	**Batticaloa lagoon**	**Pottuvill-Urani lagoon**
R. mucronata	4.75 (5.3)	42.10 (38.2)	13.84 (5.3)	23.08 (17.0)		81.96 (60.3)
R. apiculata					79.70 (53.2)	
B. gymnorrhiza			0.49 (0.1)			7.73 (5.7)
A. marina	79.80 (89.3)	68.11 (61.8)	119.72 (46.3)	107.0 (79.1)	25.91 (17.3)	
L. racemosa	4.80 (5.3)		9.26 (3.5)	4.71 (3.4)		
E. agallocha			49.81 (19.2)	0.50 (0.3)	44.16 (29.5)	46.18 (34.0)
C. decandra			2.46 (0.9)			
A. corniculatum			0.29 (0.11)			
H. littoralis			62.49 (24.2)			

*The percentage TOC contribution of each species within parentheses

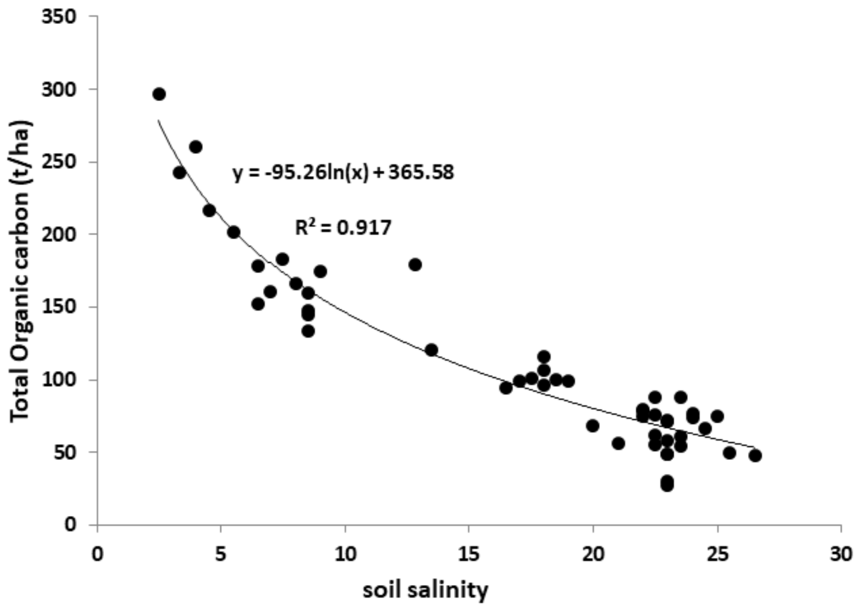

Figure 3: Relationship between TOC content in plant biomass and soil salinity of mangroves.

Data on TOC content in plant biomass and soil salinity of the study plots (total of 68) of all six study areas were pooled and analyzed. A strong positive correlation ($p < 0.001$) and a higher coefficient of determination ($R^2 = 9.177$) with non-liner relationship was observed for TOC and soil salinity of mangroves (Figure 3).

DISCUSSION

Rhizophora mucronata and *Avicennia marina* were the major constituent species in four study areas, Thondamannaru lagoon, Nayaru lagoon, Yanoya estuary and Pottuvill-Urani lagoon (Table 3). Comparable observations were reported by Amarasinghe and Balasubramaniam (1992), and Jayatissa *et al*. (2002), both species are common to many other dry zone mangrove ecosystems in Sri Lanka. A contradictory observation reported from Batticaloa lagoon with most common species were *R.apiculata* and *E. agallocha* and in Pottuvill-Urani lagoon, *A.marina* was not recorded (Table 3). This may be due to the variations in micro climatic and environmental conditions especially in the soil salinity levels. Based on the salinity data of the Batticaloa study area, revealed the low values compared with others. In general, observed species richness in mangrove areas on the west coast of Sri Lanka was greater than that on the northeast coast. Moreover, species richness in mangroves of the wet and intermediate zone was greater than that of the dry zone. Different publications explain that the distribution and establishment of mangroves are controlled by complex environmental factors. Including biotic and physico-chemical variables, which depend on geomorphic processes, determined the specific environmental conditions, with suitable mangrove species (Tomlinson 1986).

In addition to that, physiological tolerance to stresses including inundation and salinity levels, are some of the factors which have been reported to affect species distribution (Patterson and Mendelssohn 1991, McKee 1993, Chen and Twilley 1999).

A rare mangrove species, *Ceriops decandra*, was recorded in the present study at Yanoya mangrove ecosystem. In the National Red List 2012 of Sri Lanka, *C. decandra* was categorized under “Critically Endangered” species and added to the list of true mangroves recorded in Sri Lanka (personal communication). This may be the first-time scientific record of the *C. decandra* in the recent history of Sri Lanka. Higher values for species composition and diversity were recorded at Yanoya estuary (Table 3). Mean girth diameter (dbh) and height reported are also relatively high values explaining the healthy and luxuriant mangrove ecosystem among others in northeast coast of Sri Lanka.

Including above and below ground biomass and TOC embedded in plant biomass recorded northeast coast mangroves 158 – 416 Mg ha^{-1}, and 89 – 257 Mg C ha^{-1} respectively. These values are comparatively lower than that was reported by the west coast mangroves of Sri Lanka (Perera *et al.,* 2012, Perera *et al*., 2013). This may due to the lower in stand densities of some areas, such as Thondamannaru and Pottuvill-Urani lagoon. Comparing the total biomass values recorded from the present study with worldwide mangrove areas, it revealed that most of the Sri Lankan north-east coast mangroves have higher biomass retention capacity than others (Table 6). In addition to that the above ground biomass values obtained from all the mangrove areas except Thondamannaru lagoon, were comparatively high than that of the mean value (192 Mg ha^{-1}) published by the IPCC (2013).

The mean above ground tree biomass of the northeast coast of Sri Lanka was 226.34 Mg ha^{-1} (Table 4), which was higher than the common values proposed for the Southeast Asia (160 - 200 Mg ha^{-1}. The high tree biomass in the area has two possible explanations, one is that these north-east areas were highly isolated during last thirty years due to the civil war situation of the country. Very limited human

Table 6: Comparison of plant biomass (Above and below ground) values revealed from present study with publish data from worldwide mangrove ecosystems

Study area	Common mangrove species	Plant biomass			Reference
		Above ground biomass (Mg ha^{-1})	Below ground biomass (Mg ha^{-1})	Total (Mg ha^{-1})	
Halmahera, Indonesia	BG	436.00	180.70	616.70	Komiyama *et al.,* (1988)
Yanoya estuary, Sri Lanka	AM, EA, CD, LR, RM, HI, BG, AC	386.69	74.30	460.99	**Present Study**
Northwestern Australia	RS, AM	245.35	46.05	291.40	Alongi, *et al*.,(2002)
Batticaloa lagoon, Sri Lanka	EA, RA, AM	235.85	49.87	285.72	**Present Study**
Thalassery estuary, Kerala, India	AO	189.26	83.60	272.86	Vinod, *et al*., (2019)
Uppar lagoon, Sri Lanka	AM, RM, LR, EA	212.30	43.63	255.93	**Present Study**
Pottuvill-Urani Lagoon, Sri Lanka	EA, RM, BG	201.96	51.14	253.10	**Present Study**
Oligohaline zone, Sundarbans, Bangladesh	HF, EA, XM, BS, AO	154.80	84.20	239.00	Kamruzzaman *et al*., (2017)
Nayaru Lagoon, Sri Lanka	AM, RM	189.51	40.07	229.58	**Present Study**
Sofala Bay, Central Mozambique, Africa	AM	134.60	64.70	199.30	Sitoe *et al.,* (2014)
Southern Satun, Thailand	CT	92.00	87.50	179.50	Komiyama *et al*., (2000)
Ajuruteua Peninsula, Brazil	AG	91.70	87.00	178.70	Virgulino-Junior, *et al*., (2020)
Hinchinbrook Channel, Australia	RS	123.00	52.00	175.00	Matsui (2004)
Northwestern Australia	AM	132.65	28.50	161.15	Alongi *et al*., (2000)
Thondamannaru lagoon, Sri Lanka	AM, RM, LR, EA	131.78	25.75	159.53	**Present Study**
Sawi bay, Thailand	RA, AA, CT	124.40	19.50	143.90	Alongi and Dixon (2000)
Gazi Bay, Kenya	RM	62.70	18.00	80.70	Tamooh *et al*., (2009)

AM - *Avicennia marina*; AO - *Avicennia officinalis*; AA - *Avicennia alba*; AG - *Avicennia germinans*; AC - *Aegiceras corniculatum*; BG - *Bruguiera gymnorrhiza*; BS - *Bruguiera sexangula* RM - *Rhizophora mucronata*; RA - *Rhizophora apiculata*; LR - *Lumnitzera racemosa*; EA - *Excoecaria agallocha;* CD - *Ceriops decandra*; HI - *Heritiera littoralis*; HF -*Heritiera fomes*; XM - *Xylocapus mekongensis*

intervention to the mangrove ecosystems facilitated to luxuriant tree structures resulted with high biomass levels. The second reason may be the relatively high species composition and species diversity in theses six study areas compared with other mangrove areas worldwide (Table 6). Analyzing data on mangrove vegetation structure and their biomass values revealed a statistically significant ($p<0.05$) positive linear relationship to occur between both variables (Figure 2). Considering the community structural variables of study areas in northeast coast of Sri Lanka, indicated high relative frequency values for Rhizophora species among others, common to all six study areas (Table 3), may be a root for high biomass values. Ong *et al.,* (2004), reported the dominance of *Rhizophora* species, which has high above-ground biomass.

Global mangrove biomass distribution revealed that, high biomass values at lower latitude areas and decreases towards the high latitudes. Therefore, due the location of Sri Lanka, in lower latitude area, prevailing favorable climatic conditions, such as temperature, solar radiation and precipitation, facilitates to maintaining high biomass mangrove forests. The high tree biomass of mangrove forests obviously demonstrates the important role of mangrove forests as maintaining natural carbon sinks and thus in reducing carbon emissions (Siikamaki *et al*., 2012; Duarte *et al*., 2013). The results highlight the benefits of mangrove restoration for improving ecosystem carbon storage and reducing greenhouse gas (GHG) emissions (Duarte *et al*., 2013).

Many studies reported the salinity level is a driving force for distribution of mangroves (Chen and Ye, 2014; Dangremond, 2015; Kodikara *et al*., 2018), and plant species are well adapted to tolerate high salt levels in the intertidal substrate and salinity plays a vital role in their growth and productivity. Joshi and Ghose (2003) reported that maximum of the vegetation structural complexity

(CI) of mangroves has been reported from the areas with lower salinity of the western Sundarabans. Salinity effects on plant growth was described by Jalil (2002), in three ways, by limiting the water availability against the osmotic gradient, by reducing nutrient availability, by causing accumulation of Na^+ and Cl^- ions in toxic concentration causing water stress conditions, enhancing closure of stomata and reduced photosynthesis. Different soil salinity levels were recorded among total of sixty-eight study plots in six study areas, these values were then correlated with TOC capacity of the plot. A strong positive correlation ($p<0.001$) with non-liner relationship was observed for TOC and soil salinity of mangroves (Figure 3), revealed that salinity in the substrate is highly effective to the TOC retention capacity of the mangroves. High salinity levels retain low TOC retention capacity, while High TOC retention capacity will record with low salinity mangrove substratum. These relationships can be improved and be more accurate by adding data from diverse environmental and physical conditions in Sri Lanka.

CONCLUSION

Highest species diversity and biomass values (159-460 Mg ha^{-1}) were recorded at Yanoya followed by Thondamannaru and Uppar lagoons. A critically endangered mangrove species, *Ceriops decandra*, was recorded at Yanoya mangrove ecosystem. Average above ground biomass of the northeast coast of Sri Lanka was 226.34 Mg ha^{-1} which is higher than the common values proposed for the Southeast Asia (160 - 200 Mg ha^{-1}). Statistically significant linear relationships occurred between, biomass and the vegetation structure as well as soil salinity and carbon retention capacity of mangrove. Results and findings of the present study assist to add new knowledge and rationalize the conservation and management of mangrove ecosystems at northeast coast of Sri Lanka, which were highly isolated during last three decades.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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