

Ecosystem Carbon Stock of Mangroves at the Batticaloa Lagoon, Sri Lanka

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Abstract

Mangroves play an important role in sequestering organic carbon in tropical and subtropical coastal areas, accounting up to 15% of the total carbon deposited in coastal sediments. Sequestered organic carbon occurs both in standing plant biomass, as well as in the below ground root biomass and mangrove soils. Unavailability of quantitative data on carbon retention capacity of Sri Lankan mangrove ecosystems compelled the authors to carry out the present study with the objective of estimating the total ecosystem carbon content in mangrove eco systems in the Batticaloa lagoon, Sri Lanka. This is the largest lagoon situated on the east coast and the third largest brackish water system in the country. Data on vegetation

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structure were gathered according to the standard procedures and biomass of mangrove trees was determined by the Allometric method. Total Organic Carbon (TOC) in three depths, (0-15 cm, 16-30 cm and 31-45 cm) of mangrove soils was determined by dichromate-oxidation method followed by colorimetry. Total mangrove plant biomass was found to be 298 Mg ha⁻¹, of which 246 Mg ha⁻¹ was in the above ground components of the plants while 52 Mg ha⁻¹ was in the below ground components. TOC embedded in biomass was calculated to be 158 Mg C ha⁻¹ out of which 131 Mg C ha⁻¹ was found to occur in above ground and 27 Mg C ha⁻¹ in below ground components. TOC in mangrove soils (up to 45 cm depth) was revealed to be 348 Mg C ha⁻¹. The total TOC of mangrove ecosystems in the Batticaloa lagoon was calculated to be 506 Mg C ha⁻¹. Mangrove soils that sequester 68% of the organic carbon forms the largest fraction of the mangrove carbon sink. Below ground components account for only 5% of the total pool while the above ground biomass retains five times more (26%) carbon than the root biomass. These results assist pragmatic evaluation of ecological value of mangroves and justify their conservation and management.

Key words: Sri Lankan mangroves; carbon sequestration; soil carbon sinks

Introduction

Mangroves rank among the most carbon rich ecotone-ecosystems that occur along tropical and subtropical coastlines. Due to their *relatively* high primary productivity and anaerobic conditions in the inter-tidal soil/ sediment, they occupy an important role in carbon sequestration in intertidal environment (Komiyama et al., 2008; Donato et al., 2011; Hoque et al., 2011). While occupying only a small percentage (<0.1%) of earth's surface, mangroves are responsible for 10-11% of the total export of carbon to the ocean and for 8-15% of the carbon deposited in coastal sediment (Dittmar et al., 2006; Joshua et al., 2012; Jennerjahn & Ittekkot, 2002). Mangroves sequester organic carbon, in above ground plant biomass, below ground root biomass and also in soil (Alongi, 2011; Kauffman et al., 2011; World Bank, 2011). As nearly as half the biomass in trees contains carbon and large amounts of carbon are potentially stored in mangrove forests and therefore, they may be the largest stores of carbon in coastal zones (Suratman, 2008; Perera & Amarasinghe,

2016). It is estimated that carbon sequestration capacity of global mangroves is approximately 25.5 million tons of carbon per year (Ong, 1993).

The coastline of Sri Lanka is approximately 1600 km long and a narrow intertidal belt created by micro tidal conditions with tidal amplitude less than 1 m (Wijeratne, 2007). Total estimated brackish-water area of Sri Lanka is about 15800 ha (Karunathilake, 2003) and it hosts several ecosystems including mangroves that extend over an area of 15670 ha, interspersed along the coastline (Edirisinghe et al., 2012). Mangrove vegetation in Sri Lanka comprises twenty-three (23) true mangrove species and thirty-four mangrove associated plant species (Amarasinghe & Perera, 2017).

Available knowledge on carbon sequestration capacity of tropical ecosystems in Sri Lanka is scanty. Limited records are available on the standing stock of carbon in a few man-made ecosystems in Sri Lanka, i.e 90 – 104 t ha⁻¹ in home gardens (Dissanayake et al., 2009), 63 t ha⁻¹, carbon in soils of coconut plantations in the wet climatic zone, 54 t ha⁻¹ in the intermediate zone and 37 t ha⁻¹ in the dry zone (Chokkalingam & Vanniarachchy, 2011). A few records are available on above ground biomass of mangroves of Sri Lanka. Dayarathne & Kumara (2013) reported the above ground biomass (68.7-201.8 t ha⁻¹) of Rekawa mangroves, and Gunawadena et al., (2016) reported the above ground biomass estimation (of mangroves located in Negombo - Muthurajawela wetland in Sri Lanka using ALOS PALSAR Images (33-155 t ha⁻¹ with overestimation of 17%). The present study therefore was conducted with the objective of quantifying the total ecosystem carbon content, including above and below ground plant component and soils of mangrove ecosystem in the Batticaloa lagoon.

Materials and method



Study area and sites

Batticaloa lagoon lies between $7^{\circ} 24'$ - $7^{\circ} 46'$ N and $81^{\circ} 35'$ - $81^{\circ} 49'$ E, and is the largest lagoon in the east coast and the third largest brackish water system in Sri Lanka (JUGAS Ltd. (2010). This lagoon extends over 11500 ha and connects with the Indian Ocean at two locations through narrow channels. Sand bars formed due to coastal sedimentation processes serves the lagoon-ocean connection causing changes of the water salinity from 0–30 mg l^{-1} (Harris & Vinobaba, 2013). The mean annual temperature is 30°C which varies from 18°C to

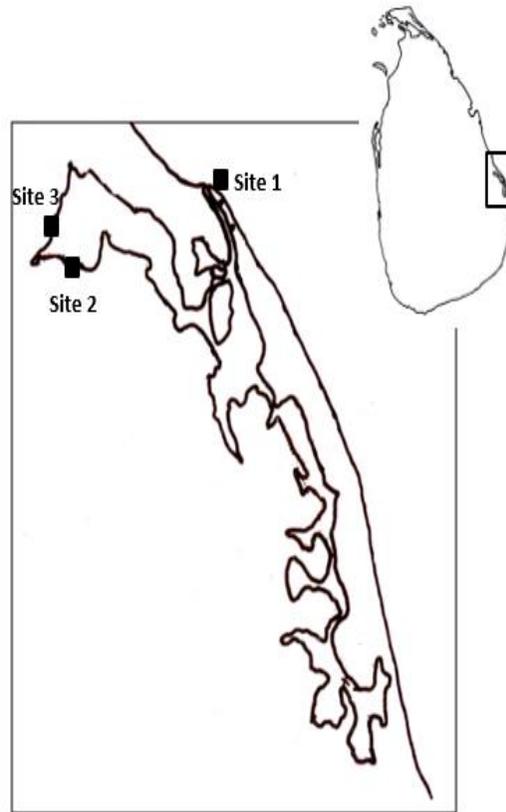


Figure. 1. Locations of study sites at Batticaloa lagoon

38°C while the annual rainfall varies within 864 - 3081mm with an average of 1500mm (Kotagama et al., 1989). The extent of mangrove vegetation reported from the area is approximately 1550 ha and they are restricted mostly to the northern end of the lagoon (Rajeeshan & Jayasingam, 2000). Therefore, three (3) study sites (Site 1, Site2 and Site 3) from northern part of the Batticaloa lagoon were selected for the study (Fig. 1). Minimum distance between two study sites was at least 2 km.

Sampling Strategy

In order to gather data on mangrove vegetation structure, including biomass and Total Organic Carbon (TOC) content in mangrove soil, 10 m wide belt transects were laid perpendicular to the shoreline at randomly selected locations in the selected study sites. Length of a transect at each site was determined by the width of the mangrove

area and visual heterogeneity of the mangrove vegetation. Total of five (5) transects, one at study Site 1 and two each at Sites 2 and 3 were laid. Maximum lengths of the transects were, 20m in Site 1, 30m in Site 2 and 30m in Site 3. Each transect was divided into 10 m x 10 m (100 m²) sub-plots and thus a total of twelve (12) sampling plots, within three (3) study sites were used for sampling. All mangrove trees in the plots were identified, numbered and mapped.

Vegetation Structure

Standard methods were adopted to quantify the major structural variables of the mangroves stands (Cintron & Novelli, 1984, Kathiresan & Khan, 2010), i.e. species richness, tree diameter at breast height (dbh) and tree height of the mangrove stands were gathered from each study plot (100 m²) in the belt transects. Plants with a stem girth, less than 2.5 cm were excluded.

Complexity Index (CI), was calculated to determine the structural complexity of the vegetation (Holdridge et al., 1971; Kathiresan & Khan 2010; Perera et al., 2013; Perera & Amarasinghe 2016). CI was calculated using data on the number of species, stand density, basal area and height.

CI = Number of species x stand density x stand basal area x stand height x 10⁻⁵

Biomass and Total Organic Carbon (TOC) content in mangrove vegetation

Allometric equations derived for individual species as well as common equations were used to determine the above ground biomass and below ground biomass of mangrove species encountered in the study plots.

The allometric equations of AGB= 0.289 (dbh)^{2.327} and BGB= 0.100 (dbh)^{2.364} were used to calculate the above ground biomass (AGB) and below ground biomass (BGB) of *Bruguiera gymnorrhiza*. The allometric equation, AGB= 0.114 (dbh)^{2.523}, was used to calculate the above ground biomass (AGB) of *Lumnitzera racemosa* while below ground biomass (BGB) was computed with BGB= 0.118 (dbh)^{2.063} (Perera et al., 2012). The above ground biomass of *Rhizophora mucronata* and *Avicennia marina* was calculated with log_e(AGB)= 6.247+2.64 log_e(dbh) and log_e(AGB)= 5.551+2.153log_e(dbh) respectively (Amarasinghe & Balasubramaniam, 1992). The biomass

of other species in the sample plots were calculated using common equations, i.e. $AGB = 0.251 \rho dbh^{2.46}$ and $BGB = 0.199 \rho 0.899 dbh^{2.46}$ (ρ – density of wood) (Komiyama et al., 2005). Standing stock of biomass values were then converted to the TOC values with the percentage TOC content in biomass of each plant component of mangrove species (Perera & Amarasinghe, 2016).

Total Organic Carbon (TOC) content in mangrove soil

A split core sampler/auger 77801 (2" x12') was used to collect soil samples. Soil samples were taken from a minimum of five randomly selected sites in each study plot (100 m²). Samples were collected from depths of 0 – 15cm, 16 – 30cm and 31 – 45cm. Composite soil samples were prepared for each depth. Soil samples were air-dried, and oven dried at 60°C for constant weight.

Chemical analysis

Total Organic Carbon (TOC) content in composite soil samples was determined using the standard wet dichromate oxidation technique, without external procedure (Anderson and Ingram, 1998; Schumacher, 2002). $K_2Cr_2O_7$ Solution was used to oxidize the TOC in acid medium. The amount of oxidized carbon in the sample was measured by determining the number of chromic ions produced during oxidation. Produced chromic ion concentration was determined using UV-visible spectrophotometer (Spectro UV-VIS Double Beam UVD-3000) at 600 nm absorbance.

Because of the incomplete oxidation of organic carbon and partially digest organic carbon in to elemental carbon forms, a correction factor was applied to elevate the accuracy of the results through adjusting the organic carbon recovery. As mean oxidation factor, 0.74 was used for the purpose.

$$\% \text{ organic carbon} = (K \times 0.1) / (W \times 0.74)$$

K = corrected concentration; W = Weight of the sample

A standard curve was plotted between absorbance and chromic ion concentration and it was used to obtain the carbon content in soil samples and in the blanks. The mean blank value was subtracted from the unknowns, which used as the value of corrected concentration, (K). The bulk density of soils in three depths (0 – 15cm, 16 – 30cm and 31 – 45cm) at the Batticaloa mangrove areas was determined with standard methods (Anderson & Ingram, 1998).

Results

Mangrove vegetation structure

A statistically significant difference was not observed between the basic vegetation structural data gathered from sub plots in the study sites and therefore, they were pooled to analyze the structure of mangrove vegetation in the Batticaloa lagoon.

Relatively high stand density (4754 trees/ha) and low species composition were revealed in the mangrove ecosystems in the Batticaloa lagoon. Only three to four true mangrove species were encountered in the subplots (100 m²) were used for the study. *Excoecaria agallocha* (3470 trees/ha) and *Rhizophora apiculata* (1054 trees/ha) were the most abundant mangrove species in the area (Table 1). *E. agallocha* recorded the highest basal area and the tree height among other species found in the area.

Table 1. Vegetation structural variables recorded from the study sites at the Batticaloa lagoon

Sampling area		Species relative frequency	Stand density (per ha)	Mean dbh (cm)	Basal area (m ² ha ⁻¹)	Mean height (m)	Complexity index
Site 1	Transect 1	EA(1%); RA(98%); Other(1%)	9300 ±1150	10.12 (2.0-20.5)	45.62	10.5 (6.5-13.5)	47.34
	Transect 2	EA(99%); Other(1%)	4350 ±510	6.68 (2.0-22.0)	24.24	4.83 (2.0-9.0)	11.77
Site 2	Transect 3	EA(79%); RA(20%); Other(1%)	2200 ±260	8.00 (1.6-35.0)	22.30	7.89 (2.0-11.0)	14.76
	Transect 4	AM(8%); EA(85%); RA(7%)	5166 ±630	7.95 (1.8-32.0)	34.35	6.36 (2.5-11.0)	41.82
Site 3	Transect 5	AM(5%); EA(92%); RA(3%)	4800 ±545	7.59 (3.0-43.0)	32.27	5.31 (2.5- 9.5)	19.01
	Mean for entire study area		EA(73%); RA(22%); AM(4%); Other(1%)	4754 ±590	8.14 (1.8-43.0)	30.01	6.6 (2.0-13.5)

AM- *Avicennia marina*, EA- *Excoecaria agallocha*, LR- *Lumnitzera racemosa*, RA- *Rhizophora apiculata*

*The mean follows standard error (±); Range of the values are presented within parentheses

Biomass and Total Organic Carbon (TOC) content

A statistically significant difference was not observed ($p>0.05$) in the biomass and TOC values recorded from the study plots in the three study sites. Therefore, the data were pooled to calculate the mean values for biomass and TOC of the mangrove plants in the Batticaloa lagoon (Table 2).

Table 2. Mangrove biomass and Total Organic Carbon (TOC) content (above and below ground) values recorded in the study sites at the Batticaloa lagoon

Sampling area	Biomass (Mg ha ⁻¹)			Total organic carbon (TOC) content (Mg C ha ⁻¹)		
	Above ground	Below ground	Total	Above ground	Below ground	Total
Study Site 1	346.49 ±2.95	73.86 ±0.55	420.35 ±3.56	193.93 ±2.33	40.02 ±0.36	233.95 ±2.68
Study Site 2	154.16 ±1.56	33.08 ±0.26	187.24 ±1.83	78.10 ±0.51	16.19 ±0.20	94.29 ±0.81
Study Site 3	238.68 ±2.43	49.87 ±0.34	288.55 ±2.76	122.78 ±1.70	24.69 ±0.23	147.47 ±1.94
Mean for entire study area	246.44 ±2.03	52.27 ±0.33	298.71 ±2.37	131.60 ±1.62	26.96 ±0.26	158.57 ±1.87

*The mean follows standard error (\pm)

Total Organic Carbon (TOC) content in mangrove soil

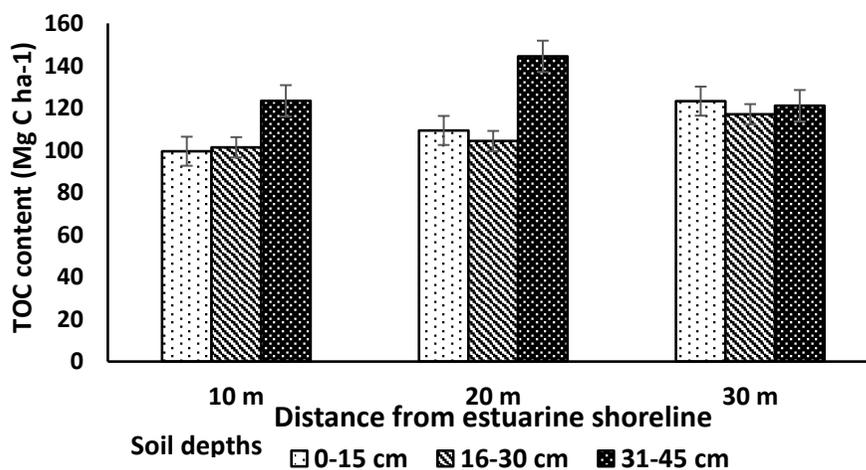
The highest values for the percentage TOC content in mangrove soil (5.55-7.30; mean=6.10) was recorded at 16-30 cm depth layer and followed by 31-45 cm depth layer (5.91-5.88; mean=5.89). The lowest percentage values (4.86-5.80; mean=5.26) for TOC was in the top soil layer (0-15 cm depth). Summary of the TOC data of the mangrove soils in the Batticaloa lagoon is presented in Table 3.

Table 3. Summary of the Total Organic Carbon (TOC) distributed among the different depth of mangrove soils at the Batticaloa lagoon

	Depth 1 (0-15 cm)	Depth 2 (16-30 cm)	Depth 3 (31-45 cm)
% TOC	5.26 ±0.50	6.10 ±0.52	5.89 ±0.43
Bulk density	1.37 ±0.02	1.30 ±0.02	1.36 ±0.02
TOC weight (Mg ha ⁻¹)	108.06 ±10.07	119.35 ±10.46	120.42 ±8.56

*The mean follows standard error (±)

The lowest values of TOC contents (99.50 -123.33 Mg C ha⁻¹) were recorded at first 10m zone from estuarine waterfront. Over-all TOC content revealed increased with estuarine shoreline to landwards (Fig. 2).

**Figure 2.** TOC contents of mangrove soil along the water-land gradient.

The TOC stock retained by the mangrove ecosystem was 506.40Mg C ha⁻¹. Soil contained 70% of the TOC stock while 25% was in above ground and 5% in the below ground components of mangrove plants (Table 4).

Table 4. Calculated Total Organic Carbon (TOC) content in mangrove ecosystem at the Batticaloa lagoon

TOC in Mangrove plants (Mg C ha ⁻¹)	Above ground components	131.60 ±1.62 (25.98%)
	Below ground components (roots)	26.96 ±0.26 (5.31%)
	Total	158.57 ±1.87 (31.30%)
TOC in Mangrove soil (Mg C ha ⁻¹)		347.83 ±33.80 (68.68%)
Total (Mg C ha ⁻¹)		506.40 ±36.04

*Standard error is in the parentheses

Discussion

Contrary to the common occurrence of *Rhizophora mucronata* and *Avicennia marina* in most Sri Lankan mangrove ecosystems in the dry zone coastal regions and mangroves of the Batticaloa lagoon are dominated by *Rhizophora apiculata* and *Excoecaria agallocha* which are often found inter-tidal areas of low salinity (Table 1). This may be due to the differences in micro climatic and environmental circumstances prevailing in the Batticaloa lagoon, especially with respect to soil salinity (Perera et al., 2013). Mangrove communities often exhibit distinct patterns of species distribution performance efficiencies depending on tolerance levels in each plant species to environmental conditions, especially soil salinity and anoxic conditions caused by inundation regimes (Joshi & Ghose 2003, Alongi, 2009). Some species such as *A. marina* do not grow in fresh water and may be considered as an obligate halophyte. High salinity tolerance of *A. marina* has been reported to possess successive of cambia that form internal phloem tissues which can store water and also repair embolism through formation of new vascular cells (Roberts et al, 2011) Others, such as *E. agallocha*, survive well in fresh water and may not have obligatory requirement for salt beyond trace amounts (Clough,1992). Under natural conditions, mangroves exhibit clear tolerance differences among species. Based on the reports of salinity tolerance levels of mangrove species (Clough,1992; Joshi & Ghose 2003; Perera et al., 2013), it was revealed that most of

the low salt tolerance species dominate the Batticaloa mangrove ecosystem.

Estimates of standard biomass both in above and below ground components provide insights into carbon allocation in plants, which is a vital information regarding local as well as regional carbon accounting or sequestration (Kairo et al., 2008). Total biomass in plants of mangrove ecosystem in the Batticaloa lagoon was estimated as 298.71 Mg ha⁻¹, out of which 246.44 Mg ha⁻¹ was in above ground and 52.27 Mg ha⁻¹ in below ground components. The amount of Total Organic Carbon (TOC) content embedded in plant biomass was calculated to be 158.57 Mg C ha⁻¹ out of which 131.60 Mg C ha⁻¹ was in the above ground and 26.96 Mg C ha⁻¹ in the belowground parts of plants (Table 2). The total standing biomass (298.71 Mg ha⁻¹) of mangrove ecosystems in the Batticaloa lagoon therefore is greater than that in the Negombo estuary (163.72 Mg ha⁻¹) located in the wet zone (Perera & Amarasinghe, 2016) and that in the Rekawa lagoon (62.4 - 201.8 Mg ha⁻¹) situated in the intermediate climatic zone (Dayarathne & Kumara, 2013). Although some mangroves around the Batticaloa lagoon are destroyed for anthropogenic reasons, the areas investigated in the present study were minimally disturbed (particularly the Sites 2 and 3) due to their remote location where the human population density is low. Remote location with poor accessibility and low human density may have saved these mangroves and their carbon sequestration capacity unlike those in the wet and intermediate zones that are located close to urbanized coastal centers.

Although above ground mangrove biomass has been studied during the past few decades (Kusmana et al., 1992; Ross et al., 2001; Coronado-Molina et al., 2004; Amarasinghe & Balasubramaniam, 1992), studies on mangrove biomass which is below ground are scanty (Komiyama et al., 2008; Pongpan, 2003; Comley & McGuinness, 2005). Considering the available records of mangrove above and below ground biomass in tropical and subtropical regions, the highest above ground biomass (460 t/ha) has been recorded for *R. apiculata* dominated mangrove forests (cultivated) in Matang, Malaysia (Putz & Chan, 1986), and the lowest (40.7 t/ha) for mangroves of East Sumatra, Indonesia which features similar species (Kusmana et al., 1992). On average, above ground biomass of mangrove values range between 280 t/ha (from Southern Ranong,

Thailand) (Tamai, et al., 1986) and 108 t/ha (from Okinawa, Japan) (Suzuki & Tagawa, 1983). The above ground biomass of mangroves in the Batticaloa lagoon (246.44 Mg ha⁻¹), can therefore be ranked relatively high among other published reports on mangrove areas in the Asian region.

Below ground biomass (BGB) calculated for mangrove ecosystems in the Batticaloa lagoon (52.27 Mg ha⁻¹) falls in between the highest BGB estimated for mangroves in the Southern Ranong, Thailand (272.9 Mg ha⁻¹) and the lowest recorded from Southern Peng-nag (28.0 Mg ha⁻¹) in the same country (Komiyama, et al., 2008; Pongparn, 2003).

According to findings of the present study, total biomass (above and below-the-ground) in the Batticaloa mangroves range between 187 – 420 Mg ha⁻¹ with an average of 259 Mg ha⁻¹ which can be considered relatively a high biomass value for a tropical ecosystem. Pattern of biomass distribution in mangroves throughout the tropics indicate that higher values occur at lower latitudes (Twilley et al, 1992). The maximum potential biomass is found in mangrove areas located between 10^o and 35^o north and south and it is about 100 and 400 t ha⁻¹ and solar energy represents a major constraint on the distribution of mangrove biomass across the latitudes (Twilley et al, 1992).

The average content of Total Organic Carbon (TOC) in mangrove with soils up to a depth of 45 cm was estimated to be 348Mg C ha⁻¹. The general pattern of distribution of TOC in tropical forests has been reported to be a decreasing trend with increasing depth (Grace et al, 2006; Ceron-Breton et al., 2011; Banerjee, et al., 2013). A reverse trend was observed in mangroves in the Batticaloa lagoon where the %TOC increases with soil depth (Table 3). This may be due to the sandy sediments in the mangrove forest floor, which accounts for relatively a high bulk density values (1.3 g cm⁻³). Levels of TOC content in mangrove soils were recorded higher than that was recorded from the soils of inland forest systems (Donato et al., 2011). The Present study revealed that TOC values of the mangrove soils in the Batticaloa lagoon, 348 Mg C ha⁻¹, which is twice higher than the TOC recorded for soils of tropical savanna forests, (146 – 198 Mg C ha⁻¹) at Yap and Palau islands in Pacific Ocean (Donato et al., 2012) and Brazil, 90 – 160 Mg C ha⁻¹(Moreno & Calderon, 2011).

Conclusion

Mangrove ecosystems in the Batticaloa lagoon which have the capacity to sequester on average, 506 Mg C ha⁻¹ of TOC therefore can be ranked superior among the other mangrove ecosystems in the region such as those in Okinawa, Japan of which the carbon sink capacity ranges between 57 – 822 Mg C ha⁻¹ (Khan et al., 2009), and Campeche, Mexico ranges 12 – 222 Mg C ha⁻¹ (Cerno-Breton et al., 2011). Findings of the present study therefore contribute to the current knowledge base on functional capacities of Sri Lankan mangroves, and therefore encourages rational decision making on conservation and management of mangrove areas for their ecological services including their carbon sequestration function and contribution to mitigate anticipated climatic changes. They also could contribute to make more accurate estimations on stocks of sequestered carbon required for carbon trading purposes such as those initiated by the United Nation's REDD+ (Reducing Emissions from Deforestation and Forest Degradation, Conservation and Enhancement of Carbon stocks, and Sustainable Management of Forest) facilities.

References

- Alongi, D. M. (2009). The energetic of mangrove forests. *Springer Science Business media B.V.*, pp 211.
<https://doi.org/10.1007/978-1-4020-4271-3>
- Alongi, D. M. (2011). Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. *Environmental Science and Policy*, 14(4), 462-470.
<https://doi.org/10.1016/j.envsci.2011.02.004>
- Amarasinghe, M. D. & Balasubramaniam, S. (1992). Structural properties of two types of mangrove stands on the northern western coast of Sri Lanka. *Hydrobiologia*. 247, 17-27.
<https://doi.org/10.1007/BF00008201>
- Amarasinghe, M. D. & Perera K. A. R. S. (2017). Historical biogeography of mangroves in Sri Lanka. *Ceylon Journal of Science*, (Special Issue) 46, 111-117.

<http://doi.org/10.4038/cjs.v46i5.7458>

- Anderson, J. M. & Ingram, J. S. I. (eds.) (1998). *Tropical soil biology and fertility*, A Handbook of methods, CAB publishing, UK.
- Banerjee, K., Sengupta, K., Raha, A. and Mitra, A. (2013). Salinity based allometric equations for biomass estimation of Sundarban mangroves, *Biomass and Bioenergy*, 56, 382-391. <https://doi.org/10.1016/j.biombioe.2013.05.010>
- Ceron- Breton, J. G., Ceron- Breton, R. M., Rangel-Marron, M., Muriel-Garcia, M., Cordova-Quiroz, A. V. & Estrella-Cahuich, H. (2011). Determination of carbon sequestration rate in soil of a mangrove forest in Campeche, Mexico, *International Journal of Energy and Environment*, 5(3), 328-336. www.naun.org/main/NAUN/energyenvironment/19-1165.pdf
- Cintron, G. & Schaeffer-Novelli, S. Y. (1984). Methods for studying mangrove structure, In: Snedaker, S. C. & Snadaker, J. (eds.), *The mangrove ecosystem: research methods*, UNESCO, Paris, 91-113.
- Chokkalingam, U. & Vanniarachchy, S. A. (2011). Sri Lanka's REDD+ potential: myth or reality? Forest carbon Asia country profile report No 1: Sri Lanka.
- Clough, B. F. (1992). Primary productivity and growth of mangrove forests. In: Robertson, A.I. & Alongi, D.M. (eds.), *Tropical mangrove ecosystems*, American Geophysical Union, Washington, USA, 225-249. URI: <http://epubs.aims.gov.au/11068/3025>
- Coronado-Molina, C., Day, J.W., Reyes, E. & Perez, B.C. (2004). Standing crop and aboveground biomass partitioning of a dwarf mangrove forest in Taylor River Slough, Florida, *Wetlands Ecology and Management*, 12 (3), 157-164. <https://doi.org/10.1023/B:WETL.0000034071.17156.c0>
- Comely, B. W. T. & McGuinness, K. A. (2005). Above and below ground biomass and allometry of four common northern

Australian mangroves, *Australian Journal of Botany*, 53, 431-436. <https://doi.org/10.1071/BT04162>

Crooks, S., Herr, D., Tamelander, J., Laffolet, D., & Vandever, J. (2011). Mitigating climate change through restoration and management of coastal wetlands and nearshore marine ecosystems: Challenges and opportunities. Environment Department paper 121, World Bank, Washington, DC:

Dayarathne, V. T. K. & Kumara, M. P. (2013). Variation of Mangrove Above-ground Dry Biomasses in Relation to Anthropogenic Disturbances, *Proceedings of the International Forestry and Environment Symposium 2013 of the Department of Forestry*, 21. <https://doi.org/10.31357/fesympo.v18i0.1874>

Dissanayake, W. A. S. S. Ranasinghe, D. M. S. H. K. & Wahala, S. (2009). Estimation of carbon stock in Kandyan homegardens located in Kandy and Matale districts in Sri Lanka, *Proceedings of the 14th International Forestry and Environment symposium*, University of Sri Jayawardenapura, Sri Lanka. 375.
<https://doi.org/10.31357/fesympo.v14i0>

Dittmar, T., Hertkorn, N., Kattner, G. & Lara, R. J. (2006). Mangroves, a major source of dissolved organic carbon to the oceans. *Global Biogeochem. Cycles* 20, GB1012.
<https://doi.org/10.1029/2005GB002570>

Donato, D., Kauffman, J. B., Murdiyarsa, D., Kurnianto, S., Stidham, M. & Kannien, M. (2011). Mangroves among the most carbon-rich forests in the tropics, *Nature Geoscience*, 4, 293-297.
<https://doi.org/10.1038/ngeo1123>

Donato, D. C., Kauffman, J. B., Mackenzie, R. A., Ainsworth, A. & Pflieger, A.Z. (2012). Whole-island carbon stocks in the tropical Pacific: Implications for mangrove conservation and upland restoration. *Journal of Environmental Management*, 97, 89-96. <https://doi.org/10.1016/j.jenvman.2011.12.004>

- Edirisinghe, E. A. P. N., Ariyadasa, K. P. & Chandani, R. P. D. S. (2012). Forest Cover Assessment of Sri Lanka, *The Sri Lankan Forester*, 34 (New series), 1-12.
- Gunawardena, A. R., Nissanka, S. P., Dayawansa, N. D. K. & Fernando, T. T. (2016). Above Ground Biomass Estimation of Mangroves Located in Negombo -Muthurajawela Wetland in Sri Lanka using ALOS PALSAR Images, *Tropical Agricultural Research*, 27 (2), 137– 146.
http://www.pgia.ac.lk/files/Annual_co
- Harris, J. M. & Vinobaba P. (2013). Assessment the Present Status of Batticaloa Lagoon, Sri Lanka by means of Water Quality, Fish Diversity Indices and Pollution Indicating Planktons. *J Biodivers Endanger Species* 1,105.
doi:10.4172/2332-2543.1000105
- Hoque, A. T. M. R., Sharma, S. & Hagihara, A (2011). Above and below ground carbon acquisition of mangrove *Kandella obovata* tree in Manko wetland, Okinawa, Japan, *International Journal of Environment*, 2011, 1, 7-13.
- Holdrige, L. R., Grenco, W. C., Hathey, W. H., Liang, T. & Tosi, J. (1971). Forest environment in tropical life zone: A pilot study, Pregaman Press, New York.
<https://lib.ugent.be/catalog/rug01:000419058>
- Jennerjahn, T. C. & Ittekkot, V. (2002). Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. *Naturwissenschaften*, 89, 23-30.
DOI: 10.1007/s00114-001-0283-x
- Joshi, H. & Ghose, M. (2003). Forest structure and species distribution along soil salinity and pH gradient in mangrove swamps of the Sundarbans, *Tropical Ecology*, 44(2), 197-206.
tropecol.com/pdf/open/PDF_44_2/44207.pdf
- Joshua, L. B., Joseph, M. S., Thomas, J. S., Christian, J. S. & Armando, H. (2012). Organic carbon burial rates in mangrove sediments: strengthening the global budget. *Global Biogeochem. Cycles* 26, GB3011.

<https://doi.org/10.1029/2012GB004375>

- Kairo, J. G., Lang at, J. K. S., Dahdouh-Guebas, F., Bosire, J. & Karachi, M. (2008). Structural development and productivity of replanted mangrove plantation in Kenya, *Forest Ecology and Management*, 255, 2630-2677.
<https://doi.org/10.1016/j.foreco.2008.01.031>
- Karunathilake, K. M. B. C. (2003). Status of mangroves in Sri Lanka, *Journal of Coastal Development*, 7, 5-9.
<https://ejournal.undip.ac.id/index.php/coastdev/article/view/383>
- Kathiresan, K. & Khan, S. A. (2010). International Training Course on Coastal biodiversity in Mangroves: Course manual, Annamalie University (CAS in Marine Biology, Parangipettai), India. 744 pp.
- Kauffman, J. B., Heider, C., Cole, C. T., Dwyer, K. & Donato, D. C. (2011). Ecosystem Carbon Stocks of Micronesian Mangrove Forests, *Wetlands*, 31,343-352.
<https://doi.org/10.1007/s13157-011-0148-9>
- Khan, N. I., Suwa, R. & Hagihara, A. (2009). Biomass and aboveground net primary production in a subtropical mangrove stand *Kandelia obovata* (S.L.) Yong at Manko wetland, Okinawa, Japan, *Wetlands Ecology & Management*, 17, 585-599. <https://doi.org/10.1007/s11273-009-9136-8>
- Komiyama, A., Pongpan, S. & Kata, S. (2005). Common allometric equations for estimating the tree weight of mangroves, *Journal of Tropical Ecology*, 21, 471-477.
<https://doi.org/10.1017/S0266467405002476>
- Komiyama, A., Ong, J. E. & Pongpan, S. (2008). Allometry, biomass and productivity of mangrove forests: A review, *Aquatic Botany*, 89, 128-137. <https://doi.org/10.1016/j.aquabot.2007.12.006>
- Kotagama, S. W., Pinto, L. & Samarakoon, J. L. (1998). Country report Sri Lanka, In: Scott, D. A. (Compiled), A Directory of

Asian Wetlands, Ramsar Site information services, Biodiversity Ecological Networks, Wetlands International, Netherlands.

- Kusmana, C., Sabiham, S., Abe, K. and Watanabe, H. (1992). An estimation of above ground tree biomass of a mangrove forest in east Sumatra, Indonesia, *Tropics*, 1, 243–257. <https://doi.org/10.3759/tropics.1.243>
- Moreno, A. N. M. & Calderon, J. H. M. (2011). Quantification of organic matter and physical-chemical characterization of mangrove soil at Hooker Bay, San Andres Island- Colombia, Proceedings of the Global conference on global warming, July, Portugal, 1-8. DOI:10.3923/jest.2016.198.207
- Ong, J. E. (1993). Mangroves - a carbon source and sink, *Chemosphere*, 27, 1097-1107. [https://doi.org/10.1016/0045-6535\(93\)90070-L](https://doi.org/10.1016/0045-6535(93)90070-L)
- Perera, K. A. R. S., Sumanadasa W. A. & Amarasinghe M. D. (2012). Carbon retention capacity of two mangrove species, *Bruguiera gymnorrhiza* (L.) Lamk. and *Lumnitzera racemosa* Willd. in Negombo estuary, Sri Lanka. *Journal of the Faculty of Graduate Studies*, University of Kelaniya, Sri Lanka. 1, 56-70 pp. <http://repository.kln.ac.lk/handle/123456789/5418>
- Perera, K. A. R. S, Amarasinghe, M. D. & Somaratna, S. (2013). Vegetation Structure and Species Distribution of Mangroves along a Soil Salinity Gradient in a Micro Tidal Estuary on the North-western Coast of Sri Lanka. *American Journal of Marine Science*, 1(1), 7-15. DOI: 10.12691/marine-1-1-2
- Perera, K. A. R. S. & M. D. Amarasinghe (2016). Atmospheric carbon removal capacity of a mangrove ecosystem in a micro-tidal basin estuary in Sri Lanka. *Journal of Atmospheric Environment*, 134, 121-128. <https://doi.org/10.1016/j.atmosenv.2016.03.034>
- Poungparn, S. (2003). Common allometric relationships estimating the biomass of mangrove forests, Ph.D. dissertation, Gifu University.

- Putz, F. & Chan, H. T. (1986). The growth, dynamics and productivity in a mature mangrove forest in Malaysia, *Forest Ecology and Management*, 17, 211-230.
[https://doi.org/10.1016/0378-1127\(86\)90113-1](https://doi.org/10.1016/0378-1127(86)90113-1)
- Rajeeshan, S. & Jayasingam, T. (2000). Preliminary study report on mangroves of Pankudaweli, workshop on Estuarine Biology, 24-26 March 2000, Sri Lanka.
- Roberts, E. M. R., Schmitz, N., Boeren, I., Driessen, T., Herrmans, K., Mey, J. D., Castele, E. V. D, Beeckman, H & Koedam, N. (2011). Successive Cambia: A Developmental Oddity or an Adaptive Structure? *PLoS ONE* 6(1): e16558.
<https://doi.org/10.1371/journal.pone.0016558>
- Ross, M. S., Ruiz, P. L., Telesnicki, G. J. & Meeder, J. F. (2001). Estimating above-ground biomass and production in mangrove communities of Biscayne National Park, Florida (USA), *Wetlands Ecology & Management*, 9, 27-37.
<https://doi.org/10.1023/A:1008411103288>
- Schumacher, B. A. (2002). Methods for determination of total organic carbon (TOC) in soils and sediments, NCEA-C-1282 EMASC-001, Ecological risk assessment support center, Office of Research and Development US. Environmental Protection Agency.
- Suratman, M. N. (2008). Carbon sequestration potential of mangroves in southeast Asia. In: F.Bravo et al. (eds.), *Managing forest ecosystems: The challenge of climate change*, Springer Science Business media, 297-315.
https://doi.org/10.1007/978-1-4020-8343-3_17
- Suzuki, E. & Tagawa, E. (1983). Biomass of a mangrove forest and a sedge marsh on Ishigaki Island, South Japan, *Japan Journal of Ecology*, 33, 231-234.
https://doi.org/10.18960/seitai.33.2_231
- Tamai, S., Nakasuga, T., Tabuchi, R. & Ogino, K. (1986). Standing biomass of mangrove forests in southern Thailand, *Journal of*

the Japanese Forestry Society, 68, 384-388.
https://doi.org/10.11519/jjfs1953.68.9_384

Twilley, R. R., Chen, R. H. & Hargis, T. (1992). Carbon sinks in mangrove forests and their implications to the carbon budget of tropical coastal ecosystems. *Water Air and Soil Pollution*, 64: 265–288. <https://doi.org/10.1007/BF00477106>