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Effect of Vegetation Structure on Carbon Assimilation Capacity of Mangrove Ecosystems in the East Coast of Sri Lanka

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Abstract

Mangroves are proven as highly potential of providing an efficient carbon sink, both on short and longer time scales. Capacity of carbon sequestration abilities of mangroves is not only a trait that is governed by their genetic make-up, but also by environmental conditions. Total capacity of carbon retention by mangrove ecosystems therefore is partly determined by their vegetation structure.

Vegetation sampling was carried out at six (6) randomly selected locations in mangrove areas of Batticaloa and Uppar lagoons on the east coast of Sri Lanka. Vegetation structure was determined by adopting standard methods and allometric relationships were used to determine mangrove plant biomass. Carbon content was determined by $K_2Cr_2O_7$ oxidation method.

Rhizophora apiculata and *Excoecaria agallocha* were the predominant species in Batticaloa mangroves, with representing high IVI values, 83.03 and 174.58 respectively, while *Rhizophora mucronata* and *Avicennia marina* were dominant Uppar lagoon with IVI values were 87.73 and 63.94 respectively, may reason of dissimilarities of soil salinity and nature of inundations. Chemical analysis revealed that nearly half of the biomass of wood and roots mangrove species (5) encountered in study area contained organic carbon. Accordingly higher TOC stock was retained by Batticaloa mangroves (149.71 t/ha) than Uppar lagoon mangroves (135.20 t/ha). Positive correlations ($p<0.05$) were revealed between TOC in mangrove trees with vegetation structural complexity (CI) and leaf area index (LAI), which easily quantify in the field.

Keywords: Coastal; Mangrove ecosystems; Rhizophora apiculata

Introduction

Mangroves are typical wetland ecosystems found in coastal deposits of mud and silt throughout the tropics and some distances into the subtropical latitudes. Mangrove communities are normally characterized by high productivity, high litter production and biomass followed by efficient in carbon sink compared to other terrestrial plant communities [1]. As approximately half of mangrove tree biomass contains organic carbon, large amounts of carbon are potentially accumulated in mangrove forests may be the largest stores of carbon in coastal zone [2].

Although mangroves are well known for high carbon assimilation and flux rates data are surprisingly lacking on whole ecosystem carbon storage [3,4]. Limited components of carbon storage in mangroves have been reported, most notably tree biomass [5,6].

According to the recent records of Department of forests, Sri Lanka, eastern province has the second largest mangrove extent divided in three districts (Trincomalee, 2595 ha, Batticaloa, 2071 ha and Ampara, 816 ha) along the east coast of Sri Lanka. Although several of research studies on Sri Lankan mangroves, studies focused on carbon sequestration and cycling are scanty and accessibility problems especially for north and east coast mangroves were occurred in last thirty years due to civil war conditions in Sri Lanka. This study was conducted with the objectives of estimate the carbon stock retaining in mangroves in two main mangrove ecosystems (Batticaloa lagoon and Upaar lagoon) at east coast of Sri Lanka, and propose a relationship between total organic carbon (TOC) content of mangroves and a easily quantifiable measurement in the field which enable to lessen the lengthily process of estimate TOC.

Materials and Method

Study area

Batticaloa lagoon is the largest among the lagoons in east coast and it is the third largest basin estuary in Sri Lanka , lies between 7^0 24’- 7^0 46’ N and 81^0 35’- 81^0 49’ E [7]. Mean depth of the lagoon recorded 1.5 m [8]. Total extent of the lagoon recorded 11500 ha, which opens into the sea through two narrow channels. Seasonal connection with the sea due to the sand bars built up by wave action during the dry period and recorded the salinity increasing up to 30 ppt at certain times (Kotagama et al., 1989). The mangrove vegetation along the lagoon covers and extent of 1550 ha [9].

Uppar/Panichchankeni lagoon is one of the larger lagoon located eastern province of Sri Lanka (8^0 05’- 8^0 11’ N and 81^0 23’- 81^0 25’ E) and total extent was recorded 2590 ha. Depth of lagoon recorded 1-2 m and opens to the sea through a narrow channel at its southern end. The much smaller lagoon of Uppu Alan is connected with the south end of Upaar Lagoon by a short Channel and tidal range being about 40 cm [7].

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Study was carried out at each three (3) study sites which randomly selected locations at mangrove areas of Batticaloa lagoon and Upaar/ Panichchankeni lagoon (Figure 1 & Table 1). Minimum distance between two study sites was at least two kilometers.

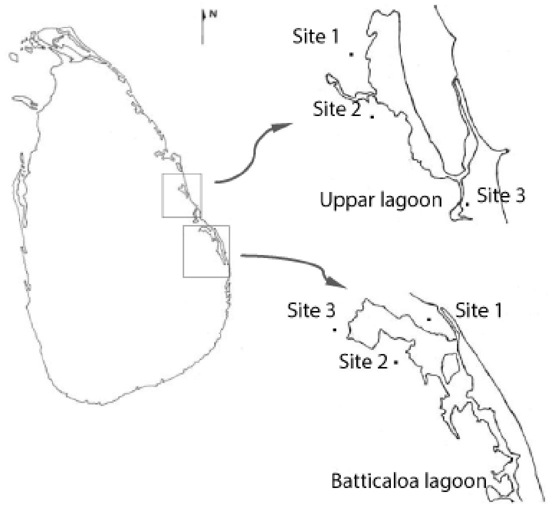

Figure 1: Study areas (Batticaloa lagoon and Uppar lagoon) and distribution of study sites.

	Study site	location
Batticaloa lagoon	Site 1	7^0 44' 50.70" N ; 81^0.41'17.67 E
	Site 2	7^0 43' 03.71" N ; 81^0.36'49.51 E
	Site 3	7^0 43' 45.06" N ; 81^0.34'40.79 E
Uppar lagoon	Site 1	8^0 05' 13.25" N ; 81^0.26'15.92 E
	Site 2	8^0 08' 22.57" N ; 81^0.23'27.13 E
	Site 3	8^0 10' 53.65" N ; 81^0.23'08.06 E

Table 1: Locations of study sites at Batticaloa lagoon and Uppar lagoon

Vegetation Structure

Data on mangrove vegetation structure i.e. species diversity, tree diameter at breast height (dbh) and tree height were measured using standard methods from each study plot (100 m2), which obtained from divided of 10 m wide belt transects laid perpendicular to the lagoon shoreline, located randomly selected places in each study area.

Trees which are equal to or exceeding 2.5 cm in dbh were measured for the purpose. Leaf area index (LAI) was determined by measuring of the difference between photon flux density beneath the mangrove canopy and top of the canopy, by using LI-COR Terrestrial radiation sensor (LI-191SA Line Quantum sensor), followed the method described by Jayakody [3,10]. Solar radiation data was gathered restricted in dry period only at the study areas.

Stand density, basal area, mean stand diameter, stand height and importance value (IVI) of constituent species was calculated according to Cintron [3,11]. Complexity of index (CI) used as an overall estimate of the structural complexity of the area was calculated for each study areas as,

Complexity of index (CI)=number of species×stand density×stand basal area×stand height×leaf area index (LAI)×10^{-5}

Biomass of Mangrove Plants

Above ground and below ground biomass of mangrove species in two study areas were estimated by the Allometric equations [12-14].

Determination of total organic carbon (TOC) in mangrove plants

Total Organic carbon contents in wood, leaf and root of five (5) mangrove species, *Rhizophora mucronata, R. apiculata, Avicennia marina, Lumnitzera racemosa, Excoecaria agallocha*, which encountered in study areas were determined.

Each five (5) samples of wood, leaf and root, respect of mangrove species, were collected from separate five matured plants. Fresh samples were air dried and followed by the oven dried at 60°C until constant weight and grind with an electrical grinder and sieve through 150 μm mesh. Roots of above ground and below ground were considered as one component of that species. Walkey and Black wet oxidation method without external heating procedure followed by colorimetric method absorbance at 600 nm, using a UV- visible spectrophotometer was applied to estimate the total organic carbon in each plant component [15,16].

Total organic carbon (TOC) in soil

Total organic carbon content of mangrove soils of Batticaloa lagoon and Upaar/Panichchankeni lagoon were determined. Composite soil samples at random points of each study plots were collected from 0-15 cm and 15-30 cm and 30-45 cm depths. Soil samples were air dried and oven dried at 60°C. up to constant weight and grinded followed by sieve though 150 μm meshes. Chemical procedure was followed by same in mangrove plant components [15,16].

Three (3) replicates of each sample were analyzed and calculated the mean percentage of organic carbon content.

Results

Mangrove Vegetation Structure

Higher stand density (4633 trees/ha) and basal area (30.01 m^2/ha) was revealed at Batticaloa lagoon than Uppar lagoon which stand density was 3555 trees/ha and basal area was 22.40 m^2/ha. *E. agallocha* was recorded the highest stand density (3022 trees/ha) and basal area (15.80 m^2/ha) among the three major mangrove species found at Batticaloa lagoon. *A. marina* is the most abundant mangrove species at Upaar lagoon with highest stand density (2307 trees/ha) and basal area (17.53 m^2/ha). Highest tree height (6.80 m) was recorded at Batticaloa lagoon mangroves than Uppar lagoon mangrove trees (5.55 m) (Table 2). Important value of index (IVI) was calculated for each species found in each study sites in two areas. Highest IVI was recorded *E. agallocha* at study site 3 of Batticaloa (506.78) followed by *A. marina* at site 2 of Uppar lagoon (221.36) and *E. agallocha* at study site 2 of Batticaloa lagoon (193.67) (Table 2). Leaf area index (LAI) was calculated form solar radiation sensor and highest LAI values were recorded from study sites at Batticaloa lagoon (Table 2). Structural complexity index (CI) of the area was calculated with vegetation structural parameters of species density, stand density, stand basal area, stand height and leaf area index (Table 2). Comparatively high values were resulted from Batticaloa mangroves (Table 2).

Study area	Upaar lagoon				Batticaloa lagoon			
	Site1	Site2	Site3	Total area	Site1	Site2	Site3	Total area
Species	Importance value of index (IVI)							
R. mucronata	68.48	55.97	40.47	87.73				
R. apiculata					262.84	106.31	38.36	83.03
A. marina	188.07	221.36	128.25	163.94	37.15		75.36	42.49
L. racemosa	21.44	22.66	120.7	39.87				
E. agallocha	21.98		10.57	8.42		193.67	506.78	174.58
Leaf area index (LAI)	4.97	4.9	2.86	4.62	6.66	4.98	5.73	5.63
Species Diversity				0.93				0.68
Complexity index (CI)	75.48	35.17	101.12	121.17	315.17	65.56	157.1	234.59

Table 2: Summary of mangrove vegetation structural parameters and diversity indices recorded in each study sites at mangroves of Batticaloa lagoon and Uppar lagoon.

Mangrove biomass and total organic carbon (TOC) content

Above and below ground biomass of the mangrove trees found in two study areas were calculated by allometric method and estimated the total biomass. Highest biomass was recorded from *A. marina* at Upaar lagoon (204.85 t/ha) followed by *R. apiculata* (142.79 t/ha) and *E. agallocha* at Batticaloa lagoon. Total of higher biomass (285.63 t/ha) was revealed from Batticaloa lagoon mangroves than Upaar lagoon mangroves (255.66 t/ha).

Species	Total organic carbon content (kg/kg biomass)		
	Wood	Leaves	Root
Rhizophora mucronata	0.562 ± 0.002	0.504 ± 0.000	0.546 ± 0.003
Rhizophora apiculata	0.561 ± 0.006	0.502 ± 0.000	0.543 ± 0.004
Avicennia marina	0.527 ± 0.002	0.500 ± 0.000	0.509 ± 0.003
Lumnitzera racemosa	0.557 ± 0.001	0.441 ± 0.002	0.543 ± 0.003
Excoecaria agallocha	0.475 ± 0.002	0.410 ± 0.003	0.462 ± 0.002

Table 3: Total organic carbon content (TOC) in biomass of main plant components (wood, leaves and root) of 5 mangrove species encountered in study areas.

Total organic carbon content in biomass of wood, leaves and roots of five (5) mangrove species encountered in the study area were determined. Approximately half of the biomass of wood and roots composed of organic carbon. Highest organic carbon content recorded in biomass of wood and roots of *R. mucronata* and *R. apiculata*, and the lowest were recorded in *E. agallocha* (Table 3). TOC in total above ground and below ground biomass of each mangrove tree was calculated and each contribution for carbon retention of the area by different mangrove species were determined (Table 4). TOC stock retained in mangrove trees observed in vary with landward direction from lagoon shore line (Figure 2)

Species	Total organic carbon (TOC) t/ha and % contributution					
	Upaar lagoon			Batticaloa lagoon		
	Above ground	Below ground	% Contribution	Above ground	Below ground	% Contribution
R. mucronata	18.9	4.15	17.4			
R. apiculata				66.35	13.31	53.2
A. marina	89.53	17.4	79.09	22.05	3.84	17.29
L. racemosa	3.8	0.91	3.48			
E. agallocha	0.4	0.09	0.36	35.93	8.21	29.48
Total	112.63	22.57		124.34	25.37	

Table 4: Total organic carbon stock (above ground and below ground) retained in each mangrove species and their contribution to total carbon retention capacity of mangroves at Batticaloa lagoon and Upaar lagoon.

Relationship between mangrove vegetation structure and total organic carbon (TOC) retention capacity

A positive correlation ($p<0.01$) was revealed between mangrove vegetation structure (complexity index –CI) and TOC of two mangrove areas at Batticaloa lagoon and Uppar lagoon (Figure 3).

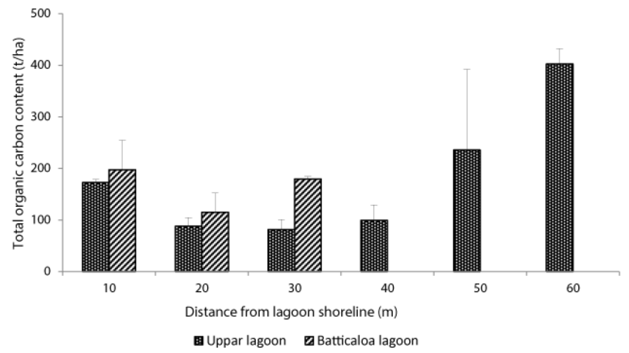

Figure 2: TOC vary with distance from lagoon shoreline

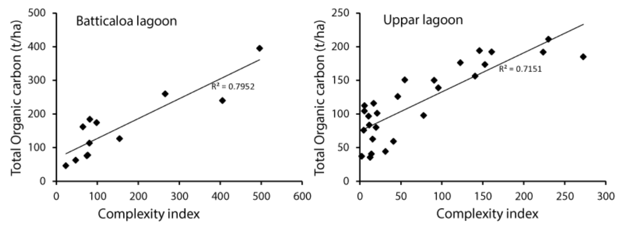

Figure 3: Relationship between TOC and vegetation structure of mangrove vegetation at Batticaloa lagoon and Upaar lagoon.

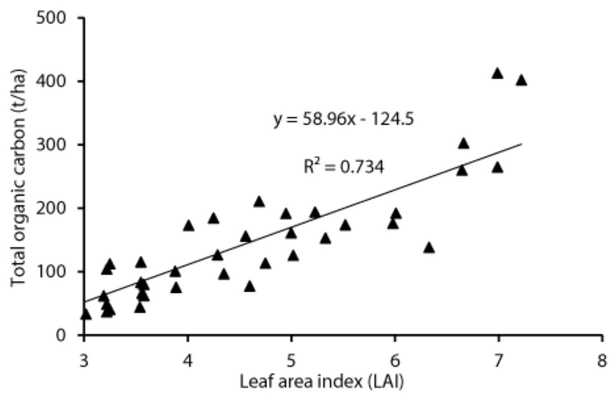

Figure 4: Relationship between TOC and leaf area index (LAI) of mangrove vegetation at Batticaloa lagoon and Upaar lagoon.

Relationship between leaf area index (LAI) and total organic carbon (TOC)

TOC and LAI data obtained from two study areas were pooled and a positive correlation ($p<0.05$) was observed between leaf area index (LAI) and TOC retention capacity of two mangrove areas at Batticaloa lagoon and Upaar lagoon (Figure 4).

Discussion

As in many other mangroves in the dry zone coastal regions in Sri Lanka, *Rhizophora mucronata* and *Avicennia marina* are the major constituent species in Upaar lagoon. A contradictory observation recorded from Batticaloa lagoon with most dominant mangrove species were *Rhizophora apiculata* and *Excoecaria agallocha* (Table 2). This may due to the dissimilarities in micro climatic and environmental conditions. Mangrove communities often exhibit distinct patterns of species distribution reported that a complex of environmental factors determines the actual distribution of plants in nature due to having different tolerance levels in each plant [17]. Pal reported that *Avicennia marina* occur dominantly in soil with high salinity and frequent and long duration tidal inundation in variations in islands of the Sundarbans [18]. It was reported the high salinity tolerances of *A. marina* with successive of cambia and functioning of the internal phloem tissues.

According to the finding recorded by Saha [19-21], local pattern of tidal inundation further influence to the soil characteristics that control species distribution in mangrove ecosystem. Joshi reported maximum vegetation complexity index was recorded at least saline and low inundated zones of Sundaraban [17].

Although ground distance between these two lagoons (Batticaloa lagoon and Uppar lagoon), not exceed 50-60 km, different in vegetation structure and species distribution symbolizes the main dissimilarities of physical and environmental factors such as, soil salinity, inundation patterns may resulted from geographical settings, depth of the lagoon and elevation of the mangroves of two areas.

Highest carbon stock were gathered near by the lagoon water front compared with next landwards 20–30 m. Although this was common to both areas, dissimilarity of magnitude was due to difference in species composition and tree density. Higher in stand density and comparatively low in dbh/gbh trees found in lagoon water front of both Batticaloa and Uppar mangroves. Dominant of *Avicennia marina* trees with higher girth diameter and low stand density, were occurred in land wards areas (50-60 m land wards) of uppar lagoon, resulted the unexpected increase of TOC in those areas. Relatively high TOC retention was recorded at Batticaloa lagoon mangroves (149.71 t/ha) than Uppar lagoon mangroves (135.2 t/ha). Although these TOC stocks are comparatively lower than that was recorded at other dry zone mangroves, higher than to the TOC stocks recorded in wet zone mangroves of Sri Lanka. TOC content of two dry zone mangroves at Kala Oya and Malwathu Oya, 204 t/ha and 165 t/ha respectively and mangroves at Negombo (wet zone) 80 t/ha [22].

According to recent reports on carbon stock estimation of *Pelliciera rhizophorae* forest at Panama average of above ground and below ground were 88 t/ha and 33 t/ha which total was recorded 121 t/ha, and results of age vise carbon stock determination in *Rhizophora stylosa* plantation at Banacon island, Philippines, which 40,20 and 15 year old trees recorded 370.7 t/ha, 174 t/ha and 208.5 t/ha respectively. These determinations of carbon stocks are slightly dissimilar with the TOC estimates of Batticaloa and Uppar lagoon mangroves due to differences of both macro and micro physical, environmental and anthropogenic factors.

Results revealed that *Rhizophora apiculata* (79.66 t/ha) and *Excoecaria agallocha* (44.14 t/ha) of Batticaloa lagoon and *Rhizophora* *mucronata* (23.05 t/ha) and *Avicennia marina* (106.93 t/ha) of Uppar lagoon were the most significant mangrove species for carbon retention function of the respect areas. This contribution varies under different climatic and environmental conditions. Perera, et al., (2012), reported the species vise contribution of carbon retention function in some mangrove areas in Sri Lanka, *Avicennia marina* (36.62 t/ha) and *Rhizophora mucronata* (27.09 t/ha) are the species that contribute most to retain carbon in Negombo estuary (wet zone). In Chilaw/ Pambala lagoon (Intermediate zone), *Rhizophora mucronata* (14.18 t/ha) and *Lumnitzera racemosa* (42.24 t/ha) were the most contributed mangrove species for carbon retention. *L. racemosa* (59.55 t/ha), and *R. mucronata* (45.75 t/ha) at Kala Oya (dry zone) and *Sonneratia alba* (92.81 t/ha) and *A. marina* (41.53 t/ha) at Malwathu Oya estuarine mangroves were dominant for carbon retention.

Complexity index (CI) represents the overall estimate of the mangrove vegetation structure of each study areas. Leaf area index (LAI) used to as additional variable than Holdridge to calculate the complexity index of this study [10,23]. Although rare to find studies focused on relationship of mangrove carbon retention with vegetation structure, several of research records found to be mangrove biomass and one of the structural variables [4,24-26]. A positive correlation ($p<0.05$) was observed between mangrove vegetation structure and total organic carbon (TOC) of mangrove areas at Batticaloa and Uppar lagoon. Determination of complexity index (CI) of mangrove is more time and labour consuming task in the field. Present study was focused to reduce these obstructions and propose a relationship between TOC and easily quantifiable variable in the field. A positive correlation was revealed between LAI and TOC. LAI can be easily determined with a quantum sensor. These relationships can be generalized and more accurate by adding of data from different environmental and physical conditions in Sri Lanka.

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