



# Ecosystem Carbon Stock of Selected Mangrove Forests of Vypin – Cochin Region, Southwest Coast of India

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## Abstract

In a tropical coastal environment, mangrove ecosystems store large amount of atmospheric carbon in biomass and soil. West coast of India host 29% of the mangrove ecosystems of the country. Putting aside the few scientific studies about the Indian mangroves system, there exist gaps in our scientific knowledge of Blue Carbon domain. This study aims to quantify the ecosystem carbon stocks potential and community structure of mangrove vegetation/ ecosystem species of Vypin– Cochin, a coastal region of the Southwest coast of India. The information on species-specific carbon storage will benefit to choose best species in the afforestation and conservation initiatives. Distribution, community structure and carbon pools of above and below ground biomass of the study area were assessed. From the analysis, it is evident that the amount of carbon stored in mangroves varies according to species, functional attributes (basal area, DBH, mean height etc.) and region. *Avicennia officinalis*, *Rhizophora mucronata*, *Acanthus ilicifolius*, *Acrostichum aureum*, *Bruguiera cylindrica* and *Sonneratia caseolaris* are the mangrove species observed from the study area. As per the community structure assessment, *A. officinalis* showed large number, frequency, density, and evenness. While considering biomass, *R. mucronata* species possess high value. The mean overall above ground biomass of the region was  $69.55 \pm 80.38 \text{ t ha}^{-1}$ . Ecosystem carbon stock of the area ranges from 17.7–138.8 with an average of  $54.3 \pm 36 \text{ t ha}^{-1}$ . Therefore, the findings described will serve as a baseline on carbon stock and mangrove stand structure of the region and their role in Blue Carbon dynamics of the Southwest Coast of India.

**Keywords** Mangrove · Carbon inventory · Blue carbon · Climate change · Tropical wetland · Biomass estimation

## Introduction

Global warming and climate change have emerged as the most crucial environmental problem, faced by humanity. While considering these issues, wetlands have become ‘significant nonentities’ in the world of global climate change (Field 2014; Cinco-Castro and Herrera-Silveira

2020). Wetlands are the major sink of carbon-containing 40% of soil organic carbon at the global level and they represent the most significant component of the terrestrial biological carbon pool (Dixon and Krankina 1995). The vegetated coastal ecosystems such as tidal marshes, mangroves and seagrass meadows store carbon in the living organisms, decomposed organic materials and in the soil column. The carbon stored, sequester and re-emit from these ecosystems refers as ‘Blue Carbon’ (Chen et al. 2012; Herr et al. 2012; Pendleton et al. 2012; Rozainah et al. 2018; Saderne et al. 2019) which plays a vital role in the global carbon balance. Carbon cycle mainly happens through processes such as photosynthesis, respiration, decomposition, and combustion (Sruthi and Ramasamy 2018). Anthropogenic emissions and deforestation cause a significant increase in carbon dioxide in the atmosphere, results in the needs of enhancement of carbon stock and sequestration potential of different ecosystems (Pachauri et al. 2014) as well as in mangroves (Sharma et al. 2020).

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Thus in the context of climate change mitigation both the reduction in CO<sub>2</sub> emission and the carbon stocking in different systems have great significance (Liu et al. 2014). For the mitigation and management of climate change impacts, the United Nations Framework Convention on Climate Change (UNFCCC) encourages, its member countries to make a proper computation on stocked, sequestered and emitted carbon (Goodwin et al. 2020; Koh and Teh 2020; Kuhl et al. 2020). Mangrove ecosystems provides a valuable ecosystem service by mitigating the climate change through carbon sequestration and storage (Inoue 2019). From the reported studies, mangroves are the potential ecosystem to store 3–5 times more organic carbon than the terrestrial ecosystem (Donato and others 2011) and this source of carbon is considered as a crucial form of Blue Carbon (McLeod et al. 2011). However, extensive deforestation and climate change impacts such as rise in sea level, increase in temperature, intensification of storms as well as tsunamis are the major disasters that have been faced by the mangrove community (Atwood and others 2017; Kathiresan and Faisal 2006).

Recently, carbon assimilated by mangrove ecosystems receives considerable attention and immense importance globally especially in the tropics (Castillo et al. 2018; Thorhaug et al. 2019). In most of the terrestrial systems, soil carbon saturation occurs through decades, but in the case of the coastal ecosystem, the sediments can store carbon dioxide for a long time and it might be over millennia. Disturbances to such carbon sinks, will release the stored carbon (for a long time) into the atmosphere and oceans, which results increase in greenhouse gases and global warming (Spivak et al. 2019).

At present, carbon stock by the coastal system in the form of ‘Blue Carbon’ has been reducing alarmingly due to the deterioration of such systems and the increase of carbon flux results severe effects on global climate (Hamilton and Friess 2018; Ouyang and Lee 2020). This has fuelled the research interest in estimating the carbon stock potential of Blue Carbon systems especially the mangroves in tropical ecosystems. Even though few literatures are available in the Indian mangrove systems (Banerjee et al. 2013; Joshi Gupta and Ghose 2014; Sanyal et al. 2018; Shrestha et al. 2019), there is diminutive data available from the Southwest coast of India on carbon dynamics (Vinod et al. 2019; Bindu et al. 2020). Even if the Southwest Coast of India has an extensive coastal zone, the baseline data on biomass analysis in mangrove ecosystem and their role in carbon stock are inattentive so far. Hence, the present study focuses to generate a baseline data on species-specific Blue Carbon storage by mangroves species of Vypin Island, Ernakulum District of Kerala, India.

## Materials and Methods

### Study Area

The study area is the selected mangrove forests of brackish water environments in Vypin Island of Ernakulum District on the Southwest Coast of India which extends from 76°12′ – 78°18′ E; 9°57′ – 10°03′ N (Fig. 1). The area is characterized as backwater bodies, marshy lands, sandy flats and alluvial plains (Shyleshchandran and Ajaykumar 2018). Mangrove vegetation in the study area were distributed along the banks of brackish water channels, estuarine and coastal flood plains as narrow belts and as continuous patches. Besides that, Ernakulam region encompasses 24% of the mangrove areas of the state (Madhusoodhanan and Vidyasagar 2012).

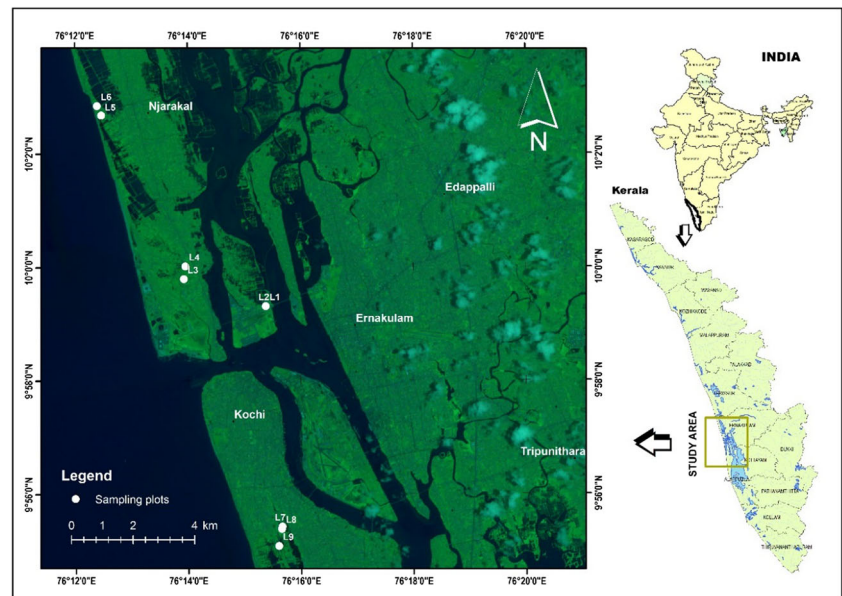
### Plot Selection and Sample Collection

For the analysis, simple random sampling method is adopted based on extent of the mangrove patch and accessibility to the selected plot. Nine plots from the study area (Goshree - L1, Belbopalam - L2, Rajagiri - L3, Ochanthuruthu - L4, Njarackel 1 - L5, Njarackel 2 - L6, Mundenveli 1 - L7, Mundenveli 2 - L8, Mundenveli 3 - L9) were selected for sampling. The minimum extent of each selected mangrove patch was One hectare. In each plot, subplots having 50 X 50 m were deployed for the enumeration of the mangrove species. For the estimation of the total biomass, above ground and below ground biomass of each species were also assessed separately. In order to calculate the biomass of each species multiple plots having size of ‘10m X 10m’ were laid randomly in each plot. Each plant species of the subplot were analysed in terms of diameter at the base, middle and top, total height, number of branches, and total number of leaf. For the biomass estimation, five species as representatives (size class - < 6 m, 6–10 m, > 10 m basal diameter) from each group of species were identified from the study area. Leaves, branches and stem of the collected plant samples were oven dried at 70 °C for 12 h, and dry weight of each species were recorded separately (Chidumayo 1990; Banerjee et al. 2013).

### Community Structure Assessment

For the community structure assessment, an intensive survey was carried out on each sampling plots ( $n = 9$ ) to record the species diversity, dominance, evenness, abundance, density, complexity index and Importance Value Index. Species diversity and dominance were calculated for all species of the plots (Magurran 2013). Shannon’s Index (Spellerberg and Fedor 2003) is employed for the biodiversity assessment and Simpson’s Index is used to measure the dominance. Abundance, density, relative abundance and relative density were also calculated in this study (Chen et al. 2018).

**Fig. 1** Study area with sampling point in Vypin - Mulavukade area of Cochin, Southwest Coast of India



Complexity index (Pool et al. 1977), and Importance value index (Joshi Gupta and Ghose 2014) were calculated by compounding relative density (RD), relative frequency (RF) and relative dominance (R Do).

### Estimation of above Ground Biomass

Vegetation biomass was calculated using the parameters such as wood density, DBH, height, number of twigs, branches and number of individuals. Wood density values of each species was also computed. Dry biomass of each plant part was estimated as per the reported studies (Chidumayo 1990; Komiyama et al. 2005; Ray et al. 2011) In the case of fern/herbs, which have scarcely branched stems, the whole plant biomass was accounted during the study.

### Estimation of Stem Biomass

Stem biomass of the plant was calculated by using the allometric equation of Komiyama et al. (2000) and it is given below:

$$B = 0.251_{\rho}(D)^{2.46}$$

Where  $B$  is the biomass in kg,  $\rho$  is the Specific gravity ( $\text{g}/\text{cm}^3$ ) and  $D$  is the Diameter at breast height (cm). The biomass of the plant was then multiplied with the number of species in the plot and the value were converted into  $\text{t ha}^{-1}$ . Diameter at Breast Height (DBH) utilized to assess the stem biomass and was measured at 1.37 m above the ground (Clough and Scott 1989; Komiyama et al. 2005).

### Estimation of Leaf Biomass

Leaves and branches of each species were collected from each plot and were dried in an oven at  $70\text{ }^{\circ}\text{C}$  until it acquired a constant dry weight. The moisture content of the leaf samples and branches were calculated on the basis of its dry-weight. Fresh weight of the leaf per twig was converted to dry weight and thus the leaf biomass of each stem was estimated.

### Above-Ground Branch Biomass Estimation

Based on the field observations, branch samples were categorised into the size class of diameter  $<6$ ,  $6-10$ ,  $>10$  cm. The collected samples were oven dried for attaining constant dry weight. Multiplying the biomass of a single branch with the total number of branches of a tree accounts the total biomass of the plant. The resultant biomass again multiply with the total number of species, which accounts the total biomass of that particular species occupied in a particular area. Values were expressed in  $\text{t ha}^{-1}$  (Ray et al. 2011).

### Carbon Pool Estimation of above Ground Biomass

Carbon pools of aboveground biomass (AGB) are determined by multiplying the biomass of individual components of a plant with their specific carbon concentration (percentage). Conversion of biomass to carbon was done by multiplying with a conversion factor having value of “0.46” (Kauffman and Donato 2012).

## Estimation of Plant Litter Biomass

Organic materials, excluding woody particles were collected from the surface layer of a mini plot of 50 X 50 cm. The total dry mass of this sub plot was scaled to a per-hectare approximation. The mean carbon concentration of the litter was calculated by multiplying with conversion factor of “0.45”(Kauffman et al. 1995).

## Estimation of Pneumatophore Biomass

Pneumatophore density was determined by counting the number of pneumatophore in the single plot of 50 X 50 cm. The mean mass of a single pneumatophore was used to calculate the total mass of pneumatophores in the sampled stand and the mean dry weight of a single one was scaled to the total area and the value is expressed in  $t\ ha^{-1}$ . The carbon conversion factor used for pneumatophore assessment is “0.39”(Mueller-Dombois and Ellenberg 1974).

## Estimation of below Ground Carbon Pool

For the estimation of the soil carbon pool in mangrove systems, the samples were taken from each sampling location using a core having a diameter of 8 cm and 30 cm in length. The collected soil column was sliced in to two and its length vary from 0 to 10 cm, 10–20 cm and it is not reach beyond 30 cm and were packed in a polyethylene cover. Total 20 soil samples were collected, for the analysis of bulk density and the organic carbon. Soil organic carbon was determined by Walkley - Black chromic acid wet oxidation method (Jackson and Barak 2005).

## Carbon Estimation

The total carbon stock ( $t\ ha^{-1}$ ) of the sample was computed by adding carbon stored in above ground carbon of tree species with the carbon stored in soil. The Carbon stock and carbon dioxide equivalents ( $CO_2e$ ) of the study area were calculated as per the procedure of Kauffman and Donato (2012).

## Results and Discussion

### Mangrove Vegetation Community Structure

A total of six species of mangrove plants, ie., *Avicennia officinalis*, *Rhizophora mucronata*, *Acanthus ilicifolius*, *Acrostichum aureum*, *Bruguiera cylindrica* and *Sonneratia caseolaris* were recorded from the study area. Their scientific name, common name and life form are given in Table 1. As per the diversity assessment, *A. officinalis* (100) and *A. ilicifolius* (77.77) showed relatively high frequency than

*A. aureum* (55.55), *R. mucronata* (44.44) and *S. caseolaris* (22.22) while the least frequency (11.11) was observed in *B. cylindrica*. Species density showed the following trend, *A. officinalis* (63.89) > *R. mucronata* (37.44) > *A. ilicifolius* (33.22) > *A. aureum* (22.22) > *S. caseolaris* (11.22) > *B. cylindrica* (0.55) (Table 2).

The most abundant species observed from the study area is *R. mucronata* (84.25) followed by *A. officinalis* (63.88), *S. caseolaris* (50.5), *A. ilicifolius* (42.71) and *B. cylindrica* (5.0). Whereas very less evenness value was observed in *R. mucronata* (0.66) and *A. ilicifolius* (0.62). Less evenness in communities might be due to the presence of dominated species like *A. officinalis*. While calculating the Shannon index highest value was observed with *A. officinalis* (2.02) due to its high evenness and richness, followed by *A. aureum* (1.49), *A. ilicifolius* (1.48), *R. mucronata* (0.97) and *S. caseolaris* (0.68). Whereas *B. cylindrica* showed zero value may be due to the least evenness and its presence only in one plot. Simpson's index showed the trend *A. officinalis* (0.84) > *A. aureum* (0.75) > *A. ilicifolius* (0.68) > *R. mucronata* (0.50) > *S. caseolaris* (0.49) and *B. cylindrica* (showed zero value). The index represents the probability that, if two individuals randomly selected from a sample will belong to different species, *A. officinalis* possess the high value, as it was the common mangrove species observed from the study area and *B. cylindrica* was observed only from a single plot.

Parameters such as basal area, density complexity index were recorded and are given in Table 3. The basal area of trees varying from 2.3 to 51.65  $m^2\ ha^{-1}$ , and the highest recorded basal area was from *R. mucronata* and the least value (2.3  $m^2\ ha^{-1}$ ) was observed from *A. ilicifolius*. Mean tree height ranges from 0.75 m to 7.3 m and *R. mucronata* showed the maximum tree height. The complexity index ( $I_c$ ) ranged from 0.002 to 94.23 and the highest complexity index showed in *A. officinalis*, because of high density, number of species and basal area. *B. cylindrica* showed the least value (0.002) might because of less in number and distribution.

When considering the importance value index (IVI) *A. officinalis* was observed with the high value of 75.95 because of high relative density, relative frequency and relative dominance, while *S. caseolaris* resulted very less IVI value of 32.24 (Table 3).

The highest species diversity was observed in L8 with five species and least was found in L2, L3 and L7. Each location was occupied with only two species, which may be attributed to the magnitude of anthropogenic pressure, intense human activities or salinity profile of the area. A total of 1517 trees belong to six species were observed from the study. Among the six species, *A. officinalis* is the dominant one with highest number (575) of species (37.90%), followed by *R. mucronata* with 337 (22.21%), *A. ilicifolius* with 299 (19.71%), *A. aureum* with 200 (13.18%), *S. caseolaris* by 101 (6.66%) and *B. cylindrica* was found in least number of 5 (0.33%).

**Table 1** Characteristics of mangrove species collected from the study area

Sl.No	Local name	Scientific name	Life form
1.	Upputha (White mangrove)	<i>Avicennia officinalis</i>	A large tree
2.	Pranthankandal (Long-fruited Stilted Mangrove)	<i>Rhizophora mucronata</i>	A large tree
3.	Chullikandal (Sea holly mangrove)	<i>Acanthus ilicifolius</i>	A small prickly leaved shrub
4.	Machintholu (Mangrove fern)	<i>Acrostichum aureum</i>	A rigid tufted fern under growth
5.	Kuttikandal (A small leaved orange Mangrove)	<i>Bruguiera cylindrica</i>	A large tree
6.	Chakkarakandal (Mangrove Apple)	<i>Sonneratia caseolaris</i>	A large tree

## Above Ground Biomass

The stored biomass in the above-ground exhibited the trend; Stem>branch>leaf. In the above ground biomass provide a significant contribution and it varies according to the number and species. Average tree height and the number of species were counted separately from each quadrat.

In the above-ground components of the woody trees, the allocation of biomass ranged between 51% and 69% to stem, 22%–33% to branch, 1%–18% to leaf in *A. officinalis* and 55% to 63% in stem, 26%–33% in branch and 2%–18% for *R. mucronata* (Table 4). For stem biomass, the values extend from 1.55 t ha<sup>-1</sup> to 54.84 t ha<sup>-1</sup>, for *A. officinalis* and 2.92 t ha<sup>-1</sup> to 146.66 t ha<sup>-1</sup> and for *R. mucronata* 0.23 t ha<sup>-1</sup> for *B. cylindrica* and 33.01 t ha<sup>-1</sup> to 45.23 t ha<sup>-1</sup> was observed from *S. caseolaris*. The branch biomass of *A. officinalis* ranged from 0.82 t ha<sup>-1</sup> to 22.5 t ha<sup>-1</sup> and for *R. mucronata* it ranged from 1.4 t ha<sup>-1</sup> to 76.77 t ha<sup>-1</sup>. The value of *B. cylindrica* is 0.15 t ha<sup>-1</sup> and for *S. caseolaris* it ranged from 6.55 t ha<sup>-1</sup> to 11.61 t ha<sup>-1</sup>.

In the case of *A. officinalis*, the observed leaf biomass ranges from 0.64 to 4.93 t ha<sup>-1</sup>. Whereas for *R. mucronata*, it varies from 0.96 to 6.62 t ha<sup>-1</sup>. The value for *B. cylindrica* was 0.08 t ha<sup>-1</sup> and for *S. caseolaris*, it ranged from 2.77 to 4.48 t ha<sup>-1</sup>. In the study area, litter and pneumatophore contribute only a small fraction of biomass.

While considering the above-ground biomass of the study area, the species wise biomass contribution is in the order *R. mucronata* < *A. officinalis* < *S. caseolaris* < *B. cylindrica* < *A. ilicifolius* < *A. aureum*. *A. officinalis* has a mean AGB of 23.29 t ha<sup>-1</sup> and *R. mucronata* has a mean AGB of 78 t ha<sup>-1</sup>. *B. cylindrica* was observed from a single plot and it possess very less in number, while its AGB was 0.46 t ha<sup>-1</sup>. *S. caseolaris* resulted a mean AGB of 51.83 t ha<sup>-1</sup>. *A. ilicifolius* and *A. aureum* were considered as dwarf species and their total AGB have calculated with allometric equations. *A. ilicifolius* and *A. aureum* had an average AGB of 0.02 t ha<sup>-1</sup> and 0.006 t ha<sup>-1</sup> respectively.

The L1 region showed the highest value of AGB (257.36 t ha<sup>-1</sup>) and plot in L7 had the least value of 3.02 t ha<sup>-1</sup>. Comparatively L1, L2, L3, L8 and L9 showed relatively high AGB value. Whereas L4, L5, L6 and L7 showed the least value where species occurrence and number was very less (Fig. 2).

## Soil Carbon Stock

Variation in temperature, bulk density, organic carbon and soil carbon were analysed and are given in Table 5. Soil temperature extends from 27.3 °C to 31.9 °C and the bulk density values ranges from 0.43 to 2.21 g/cm<sup>3</sup>. Values of organic carbon varies from 0.5% to 2.7%. Soil carbon stock in plots

**Table 2** Biodiversity and characteristic of plant species collected from the study area

Sl.no	Parameter	<i>Avicennia officinalis</i>	<i>Rhizophora mucronata</i>	<i>Acanthus ilicifolius</i>	<i>Acrostichum aureum</i>	<i>Bruguiera cylindrica</i>	<i>Sonneratia caseolaris</i>
1.	Number	575	337	299	200	5	101
2.	Frequency	100	44.44	77.77	55.55	11.11	22.22
3.	Density	63.89	37.44	33.22	22.22	0.55	11.22
4.	Abundance	63.88	84.25	42.71	40	5.00	50.5
5.	Evenness	0.85	0.66	0.62	0.89	1	0.996
6.	Shannon index	2.02	0.97	1.48	1.49	0	0.6892
7.	Simpson index	0.84	0.50	0.68	0.75	0	0.496
8.	Relative abundance	37.90	22.21	19.71	13.18	0.33	6.66

**Table 3** Other features on biodiversity observed from the study area

Species	Basal area (m <sup>2</sup> ha <sup>-1</sup> )	No. of Species	Density	Mean Height (m)	Ic	R D (%)	R F (%)	R Do (%)	IVI
<i>A. officinalis</i>	48.86	575	63.89	5.2	94.23	37.90	32.14	5.90	75.95
<i>R. mucronata</i>	51.65	337	37.44	7.3	66.79	22.21	14.28	18.08	54.58
<i>A. ilicifolius</i>	2.3	299	33.22	1.2	0.29	19.71	24.99	11.80	56.51
<i>A. aureum</i>	3.1	200	22.22	0.75	0.10	13.18	17.85	8.85	39.89
<i>B. cylindrica</i>	34.61	5	0.55	3.1	0.002	0.32	3.57	36.90	40.79
<i>S. caseolaris</i>	27.17	101	11.22	4.4	1.35	6.65	7.14	18.45	32.24

extends from 9.87 to 23.49 t ha<sup>-1</sup>. The average soil carbon stock of all plots was 18.26 ± 3.9 t ha<sup>-1</sup>. Studies postulates the increase in soil temperature due to climate change that might have a negative impact on the carbon stock potential of mangrove ecosystems and it possess negative correlation between soil temperature and carbon stock potential (Matsui et al. 2012).

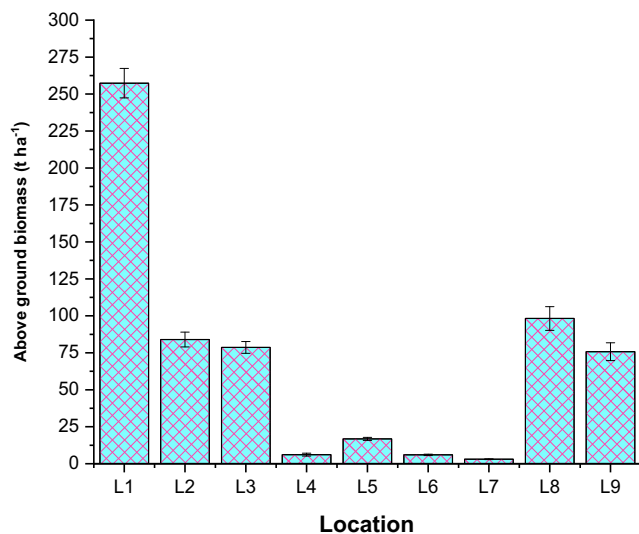
## Carbon Stock

### Carbon Stock in Stem, Branch and Leaf

As per the results of carbon stock analysis in stem, *R. mucronata* showed very high carbon (23.32 t ha<sup>-1</sup>) followed by *S. caseolaris* (17.99 t ha<sup>-1</sup>), *A. officinalis* (7.05 t ha<sup>-1</sup>)

**Table 4** Variation in biomass (t ha<sup>-1</sup>) of the different mangrove communities in the study area

Location	Species	Stem (t ha <sup>-1</sup> )	Branch (t ha <sup>-1</sup> )	Leaf (t ha <sup>-1</sup> )	Pneumatophore (t ha <sup>-1</sup> )	Litter (t ha <sup>-1</sup> )	AGB (t ha <sup>-1</sup> )
L1	<i>Avicennia officinalis</i>	16.17	6.14	4.93	0.02	0.80	27.26
	<i>Rhizophora mucronata</i>	146.66	76.77	6.62	–		230.05
	<i>Acanthus ilicifolius</i> (shrub)	–	–	–	–		0.05
L2	<i>Avicennia officinalis</i>	14.33	9.79	1.16	0.014	0.36	25.29
	<i>Rhizophora mucronata</i>	38.52	18.36	1.82	–		58.7
L3	<i>Avicennia officinalis</i>	54.84	22.5	1.27	–	–	78.61
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.01
L4	<i>Avicennia officinalis</i>	3.88	1.07	0.71	0.021	0.50	5.68
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.004
	<i>Bruguera cylindrica</i>	0.23	0.15	0.08	–		0.46
L5	<i>Acanthus ilicifolius</i>	–	–	–	–	1.49	0.04
	<i>Avicennia officinalis</i>	6.95	3.34	1.18	0.010		11.48
	<i>Acrostichum aureum</i> (ferm)	–	–	–	–		0.005
	<i>Rhizophora mucronata</i>	2.92	1.4	0.96	–		5.28
L6	<i>Avicennia officinalis</i>	3.09	1.89	0.98	0.02	0.81	5.97
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.01
	<i>Acrostichum aureum</i>	–	–	–	–		0.009
L7	<i>Avicennia officinalis</i>	1.55	0.82	0.64	–	–	3.01
	<i>Acrostichum aureum</i>	–	–	–	–		0.011
L8	<i>Avicennia officinalis</i>	15.66	4.61	3.6	0.08	–	23.96
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.004
	<i>Acrostichum aureum</i>	–	–	–	–		0.005
	<i>Rhizophora mucronata</i>	14.69	2.2	1.09	–		17.98
	<i>Sonneratia caseolaris</i>	45.23	6.55	4.48	–		56.26
L9	<i>Avicennia officinalis</i>	21.58	5.55	1.23	0.02	–	28.38
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.005
	<i>Acrostichum aureum</i>	–	–	–	–		0.004
	<i>Sonneratia caseolaris</i>	33.01	11.61	2.77	–		47.39



**Fig. 2** Distribution of above ground biomass ( $\text{t ha}^{-1}$ ) in different plots of the study area

and *B.cylindrica* ( $0.10 \text{ t ha}^{-1}$ ). In case of branch carbon stock, the trend observed was similar to stem (Table 6). *R. mucronata* showed high carbon stock ( $11.35 \text{ t ha}^{-1}$ ) followed by *S.caseolaris* with  $4.17 \text{ t ha}^{-1}$ , *A. officinalis* with of  $3.89 \text{ t ha}^{-1}$  and least carbon content was found in *B.cylindrica* with  $0.06 \text{ t ha}^{-1}$ . Where as in the case of leaf carbon stock *S.caseolaris* showed high mean value of carbon ( $1.66 \text{ t ha}^{-1}$ ) followed *Mucronata* with  $1.75 \text{ t ha}^{-1}$  and *A. officinalis* with of  $0.81 \text{ t ha}^{-1}$ , *B.cylindrica* showed least mean value of  $0.03 \text{ t ha}^{-1}$ .

### Carbon Stock in Species

Based on the species wise carbon stock analysis *R.Mucronata* showed very high mean above-ground carbon stock (AGCS) of  $35.88 \text{ t ha}^{-1}$  and *A.aureum* was observed with least mean value of  $0.004 \text{ t ha}^{-1}$ . *A. officinalis* and *Caseolaris* showed mean AGCS values of  $10.83 \text{ t ha}^{-1}$  and  $23.84 \text{ t ha}^{-1}$

**Table 5** Result of the soil quality analysis

Plot	Bulk density ( $\text{gm/cm}^3$ )	Organic carbon (%)	Soil carbon ( $\text{t ha}^{-1}$ )
L1	0.74	1.21	20.46
L2	1.03	0.9	18.49
L3	0.76	2.3	17.48
L4	0.80	2.1	16.86
L5	0.43	2.35	9.87
L6	0.87	2.7	23.49
L7	1.05	1.73	18.25
L8	2.21	0.5	22.06
L9	0.98	0.88	17.35

respectively. *B. cylindrica* and *A.aureum* possessed a mean value of  $0.57 \text{ t ha}^{-1}$  and  $0.003 \text{ t ha}^{-1}$  respectively.

The present study reveals that among all mangrove species, *R. mucronata* exhibit higher potential in carbon stock, it clearly can be observed in plot one. Carbon stock in litter had an average value of  $0.35 \text{ t ha}^{-1}$  and pneumatophore had a mean value of carbon stock  $0.010 \text{ t ha}^{-1}$ . Therefore, litter and pneumatophores in the study area do not possess any significant carbon stock potential as comparable to the AGCS (Table 6).

### Ecosystem Carbon Stock

Carbon stock in mangrove biomass and sediment carbon stock are the important carbon sinks in coastal and inland wetlands of tropical countries. The ecosystem carbon stock of the area ranges from  $17.6$ – $138.8$  with an average of  $54.3 \pm 36 \text{ t ha}^{-1}$ . The greenhouse gas inventories generally represent the carbon stock in terms of  $\text{CO}_2$  equivalents. The observed  $\text{CO}_2$  equivalent of the study area was in the range of  $64.6$  to  $509.6$  with an average of  $179.9 \pm 132.2 \text{ t ha}^{-1}$ . Total above ground carbon stock, soil carbon stock, carbon stock of the study plot and  $\text{CO}_2$  Equivalents were depicted in Fig. 3. The ecosystem carbon stock of each plot was calculated and the values were comparable with the carbon stock value of mangroves in China which ranges from  $28.8 \text{ t ha}^{-1}$  to  $355.25 \text{ t ha}^{-1}$  (Liu and others 2014).

### Tree Biomass Allocation

The mean AGB of the present study ( $69.55 \pm 80.38 \text{ t ha}^{-1}$ ) is comparable to that in Mahanadi Mangrove Wetland (Sahu 2016), Sundarbans (Mitra 2011, Choudhuri 1991) and Shigaki Island of South Japan (Suzuki and Tagawa 1983). The AGB of study possess similarity with CGM Biosphere Reserve ( $72.8 \text{ t ha}^{-1}$ ) and in Mekong Delta ( $86.5 \text{ t ha}^{-1}$ ) of Vietnam where *Rhizophora sp.* was the dominant species (Nam et al. 2016). Above ground biomass mean value of *Avicennia officinalis* showed close similarity with that observed from *Avicennia alba* ( $26.03 \text{ t ha}^{-1}$ ) in the central region of Sundarbans (Mitra et al. 2011). AGB value of *Sonneratia caseolaris* showed a comparable result with that of *Sonneratia apetala* ( $47.68 \text{ t ha}^{-1}$ ) in Sundarbans (Banerjee and others 2013). *Acanthus ilicifolius* and *Acrostichum aureum* were observed with a comparable AGB values ( $0.03 \text{ t ha}^{-1}$  to  $1.4 \text{ t ha}^{-1}$ ) that reported from the herbs of Sundarbans (Joshi Gupta and Ghose 2014).

The leaf biomass of *A. officinalis* and *R.mucronata*, is not comparable with other species. Litter and pneumatophore contributed only a small fraction of biomass in the study area. The litter biomass of the present study concurs with the results of Bay of Sabol (Sitoeet al. 2014). The observed pneumatophores biomass result ( $0.2 \text{ t ha}^{-1}$ ) were as close to that reported from Sundarbans (Joshi Gupta and Ghose 2014).

**Table 6** Results of above ground biomass carbon stock by mangroves between plots and species of the study area

Location	Species	Stem (t ha <sup>-1</sup> )	Branch (t ha <sup>-1</sup> )	Leaf (t ha <sup>-1</sup> )	Pneumatophore (t ha <sup>-1</sup> )	Litter (t ha <sup>-1</sup> )	AGCS (t ha <sup>-1</sup> )
L 1	<i>Avicennia officinalis</i>	7.44	2.82	2.27	0.006	0.36	12.91
	<i>Rhizophora mucronata</i>	67.46	35.31	3.05	–		105.82
	<i>Acanthus ilicifolius</i> (shrub)	–	–	–	–		0.02
L 2	<i>Avicennia officinalis</i>	6.59	4.50	0.53	0.005	0.16	11.79
	<i>Rhizophora mucronata</i>	17.72	8.45	0.84	–		27.002
L 3	<i>Avicennia officinalis</i>	25.23	10.35	0.58	–	–	36.16
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.005
L 4	<i>Avicennia officinalis</i>	1.78	0.49	0.33	0.008	0.23	2.83
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.002
	<i>Bruguiera cylindrica</i>	0.10	0.06	0.037	–		0.19
L 5	<i>Acanthus ilicifolius</i>	–	–	–	–	0.67	0.02
	<i>Avicennia officinalis</i>	3.19	1.54	0.54	0.004		5.28
	<i>Acrostichum aureum</i> (fern)	–	–	–	–		0.003
L 6	<i>Rhizophora mucronata</i>	1.35	0.64	0.44	–	0.36	2.43
	<i>Avicennia officinalis</i>	1.42	0.87	0.45	0.005		3.12
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.005
L 7	<i>Acrostichumaureum</i>	–	–	–	–	–	0.004
	<i>Avicennia officinalis</i>	0.71	0.37	0.29	–		1.38
	<i>Acrostichum aureum</i>	–	–	–	–		0.005
L 8	<i>Avicennia officinalis</i>	7.21	2.12	1.66	0.035	–	11.01
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.002
	<i>Acrostichum aureum</i>	–	–	–	–		0.002
	<i>Rhizophora mucronata</i>	6.75	1.012	0.50	–		8.27
	<i>Sonneratia caseolaris</i>	20.81	3.01	2.06	–		25.88
L 9	<i>Avicennia officinalis</i>	9.93	2.55	0.57	0.008	–	13.05
	<i>Acanthus ilicifolius</i>	–	–	–	–		0.002
	<i>Acrostichum aureum</i>	–	–	–	–		0.002
	<i>Sonneratia caseolaris</i>	1.38	5.34	1.28	–		8.001

Bulk density of soil was similar to the value reported in Can Gio Mangrove Biospheres Reserve in Mekong delta (0.5 g/cm<sup>3</sup>) of Vietnam. Values of organic carbon percentage was comparable to that (2.29%) in the KienVang Protection Forest in Mekong delta (Nam et al. 2016).

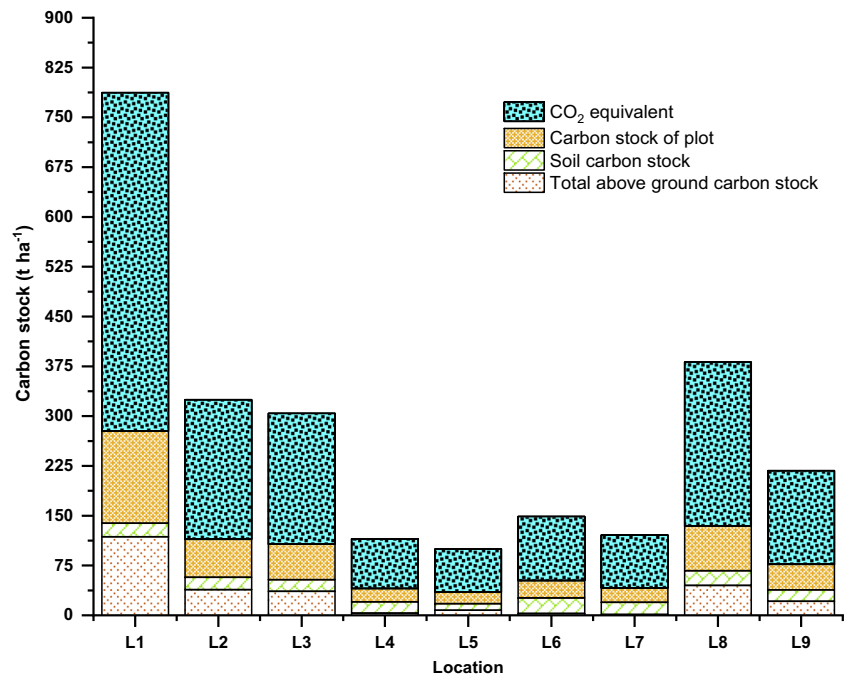
## Conclusion

The present study examined the community structure, and carbon stock potential of mangrove systems in Vypin region of Cochin coast, and the observed results vary according to spatial locations, species composition, and soil properties. It is evident that the carbon stock potential of mangroves has proven their efficiency to store more carbon and can consider it as a proficient sink of carbon. As per the community structure assessment, *Avicennia officinalis* dominated with large number, frequency, density and evenness. While considering the

biomass, the species *Rhizophora mucronata* hold very high value. The assessment result of carbon stock proved that the species *Rhizophora mucronata* have a significant potential to capture the atmosphere carbon to soil. Mangrove ecosystems have a remarkable role to reduce the atmospheric CO<sub>2</sub> by plant biomass and simultaneously enhance the soil carbon pool. The ecosystem carbon stock of the study area ranged between 17.7–138 with an average of 54.3 ± 36 t ha<sup>-1</sup> and it reveal that the mangrove system of the region play a significant role in Blue Carbon dynamics of the region. The findings of the study would help in assessing carbon stock of Southwest Coast of India to a greater extent and can support the mangrove conservation and restoration programme. In addition, the information on species-specific carbon storage will help us to choose best species in the afforestation and conservation initiatives. Hence, the present study has the potential to become a blueprint for the carbon stock of the region and will be highly significant for climate change mitigation strategies.



**Fig. 3** Carbon stock distribution ( $\text{t ha}^{-1}$ ) in different plots of the study area



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## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

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