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Tree Biomass and Carbon Sequestration of Three Mangrove Species Planted in Bogachattor Forest Beat in the Chattogram Coast, Bangladesh

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Abstract

The global climate is changing significantly due to deforestation, forest degradation and burning of fossil fuels. Afforesting along the coastal belt, Bangladesh may play a significant role in mitigating global climate change. This study quantified the tree-biomass and carbon mass in the Bogachattor forest beat of the Sitakunda forest range under the Chattogram coastal forest division. The study estimated that the total biomass of *Sonneratia apetala*, *Avicennia officinalis*, and *Excoecaria agallocha* were 432.61±82.02, 251.15±23.71, and 59.08±5.04 t ha^{-1}, respectively, with the mean annual increment of 21.63±4.10, 12.56±1.19, and 2.95±0.25 t ha^{-1} y^{-1}, respectively. Furthermore, the total carbon mass were 216.31±41.01, 125.58±11.85, and 29.54±2.52 t C ha^{-1} for *S. apetala*, *A. officinalis*, and *E. agallocha*, respectively, with the mean annual increment of 10.82±2.05, 6.28±0.59, and 1.48±0.13 t C ha^{-1} y^{-1}, respectively. Overall, the findings indicated that *S. apetala*, *A. officinalis*, and *E. agallocha*-based afforestation has the potential to mitigate climate change. The findings can be helpful for researchers and policymakers on the national and global scale to mitigate climate change.

Keywords: *Mangrove tree species; Coastal afforestation; Carbon sequestration*; *Aboveground biomass; Belowground biomass.*

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বৈশ্বিক জলবায়ু সুস্পষ্টভাবে পরিবর্তন হচ্ছে, এবং এক্ষেত্রে বন-ধ্বংস, বনের ক্ষয় ও জীবাশ্ম জ্বালানি দহন প্রধানতমঃ কারণ। বাংলাদেশ তার উপকূলীয় এলাকায় বনায়ন করে জলবায়ু পরিবর্তন রোধে বিশেষ ভূমিকা পালন করতে পারে। এই গবেষণাটি চট্টগ্রাম উপকূলীয় বনায়ন বিভাগের অধীনস্থ সীতাকুন্ড ফরেষ্ট রেঞ্জের বগাচত্বর বনবিটে গাছের জৈববস্তুপুঞ্জ (Biomass) উৎপাদন এবং তার কার্বন (Biomass-carbon) সংবন্ধনের পরিমাণ হিসাব করেছে। গবেষণাটিতে দেখা গেছে যে, কেউড়া (*S. apetala*), বাইন (*A. officinalis*) এবং গেওয়া (*E. agallocha*) এই তিনটি বৃক্ষ প্রজাতির মোট জৈববস্তুপুঞ্জের ঘনত্ব হেক্টর প্রতি যথাক্রমে ৪৩২.৬১±৮২.০২, ২৫১.১৫±২৩.৭১, এবং ৫৯.০৮±৫.০৪ টন। প্রজাতিগুলোর মোট জৈববস্তুপুঞ্জ হেক্টর প্রতি যথাক্রমে ২১.৬৩±৪.১০, ১২.৫৬±১.১৯, এবং ২.৯৫±০.২৫ টন করে বার্ষিক-গড়-বৃদ্ধি হয়েছে। অধিকন্তু, তাদের মোট জৈববস্তুপুঞ্জ-কার্বন ঘনত্ব পাওয়া যায় যথাক্রমে হেক্টর প্রতি ২১৬.৩১±৪১.০১, ১২৫.৫৮±১১.৮৫, এবং ২৯.৫৪±২.৫২ টন। প্রজাতিগুলোর বায়োমাস-কার্বনের বার্ষিক গড় বৃদ্ধি পাওয়া যায় যথাক্রমে হেক্টর প্রতি ১০.৮২±২.০৫, ৬.২৮±০.৫৯, এবং ১.৪৮±০.১৩ টন। এই গবেষণার ফলাফল এটাই নির্দেশ করেছে যে, কেউড়া, বাইন এবং গেওয়া ভিত্তিক উপকূলীয় বনায়ন জলবায়ু পরিবর্তন মোকাবেলায় সম্ভাবনাময়। এই গবেষণার ফলাফলগুলো জলবায়ু পরিবর্তন ও এর প্রভাব মোকাবিলা সংক্রান্ত কাজের সাথে দেশীয় ও বৈশ্বিক পর্যায়ে সংশ্লিষ্ট গবেষক এবং নীতিনির্ধারকগণের কাজে লাগবে।

1. Introduction

Global climate is facing significant changes caused mainly by deforestation, forest degradation, and the burning of fossil fuels [1]. Temperature and precipitation changes influence hydrologic processes and water resources availability [2, 3]. It predicts that global temperatures would be likely to rise between 1.4 and 5.8°C from 1990 to 2100 if greenhouse gas emissions do not reduce [4].

As a low-lying country, Bangladesh is facing the early impacts of climate change. The influence of climate change is severe, making the country one of the world's disaster-prone countries. Mangrove forests, covering 16 million ha of tropical and subtropical regions, can mitigate climate change by contributing carbon content stabilization in the atmosphere [5, 6]. Besides, mangrove and coastal forests provide a wide range of services for human well-being, such as disaster mitigation, protection of lives and resources, living standard and resource development, and protection of the environment.

Bangladesh has a long coastal zone, covering 19 districts out of 64 [7, 8]. The coastal afforestation program in Bangladesh was initiated in 1966 by the Forest Department. The Sundarbans' protection of the southwestern part of the country from natural disasters paved the way to initiate this program [9]. Coastal afforestation is a cheaper and ecologically more beneficent way to protect the coastal areas and offshore islands from cyclone and storm surges than any other measure [10].

Trees play as an essential carbon sink and biomass source, including timber, fuelwood, food, and fodder. Aboveground forest biomass comprises about 70–90% of total forest biomass [11]. Among the six-carbon pools (aboveground trees, aboveground non-tree, belowground roots, litter, deadwood, and soil organic matter), the aboveground biomass of the trees is ecologically significant.

Studies were conducted for estimating mangrove tree carbon in Mahanadi mangrove wetland of East Coast of India [12], in the naturally growing mangrove forest of Peninsular Malaysia [13], in the artificially and naturally regenerated mangrove ecosystem in the Mekong Delta [14], in the mangrove forests along the Pacific and Caribbean coasts of Honduras [15], in the Sofala Bay mangrove forests of Mozambique [16], in the mangrove forests in Southeast Mexico [17], and in the mangrove ecosystems in northwestern Madagascar [18]. In Bangladesh, studies on carbon estimation in the mangrove ecosystems were conducted by Rahman *et al.* [19] in the Sundarbans, Hossain *et al.* [20] in the Sundarbans, Ahmed and Kamruzzaman [21] in the Sundarbans, Kamruzzaman *et al.* [22] in the Sundarbans, Miah *et al.* [23] in the Chittagong coastal forest division (non-mangrove trees in the mangrove soil), Miah and Chowdhury [24] for measuring organic carbon in the soils of the Bogachattor, Chittagong, Miah and Raihan [25] in the Cox’s Bazar for Casuarina shelterbelt, Miah and Hossain [26] in the Cox’s Bazar. However, the study related to the carbon sequestration potential of the mangrove trees of coastal afforestation in the Chattogram coast of Bangladesh is insufficient. Hence, this study attempted to enrich the knowledge pool of carbon sequestration by the three mangrove tree species commonly planted in the coastal afforestation programs in Bangladesh. The study's specific objectives were to estimate the biomass growth and carbon sequestration potential of three mangrove tree species planted in the coastal afforestation located along the shoreline of Sitakunda under the Chattogram coastal forest division of Bangladesh.

2. Materials and Methods

The study was conducted in the coastal afforestation sites of Chattogram. The study took one forest beat under Chattogram Coastal Afforestation Division for observing the carbon stock of the existing artificial plantation of mangrove species. The duration of the study was from April 2016 to June 2016.

2.1 Description of the study area

The studied area consists of the Sitakunda coastal forest range at Sitakunda Upazila under the Chattogram coastal forest division. The total area of coastal plantation under Sitakunda coastal afforestation sites is 3830.16 ha. Sitakunda Upazila lies between 22º30' N to 22º54' N latitude and 91º27' E to 91º45' E longitude [27]. Sitakunda forest range comprises Bansbaria beat, Bhaterkhil beat, Bogachattor beat, and Bagkhali beat (*pers. comm.*).

Among the four forest beats, Bogachattor was selected for this study purposively for its immense success in mangrove plantations. The study area is about 6 kilometers away from Boro Dargar Hat, Sitakunda. In the study area, the forest department raised all the plantations on newly accreted coastal land. The land surface is flat, stable, and muddy [28]. The area inundates twice a day by the Bay of Bengal's saline water, which is subject to heavy siltation. In the dry season, the upper part of this coastal land remains dry, and the sea-facing lands get inundated twice a day. The area is typically subtropical, with a long dry season extending from September to April. Figure 1 shows the location of the Bogachattor forest beat under coastal forest division in Chattogram.

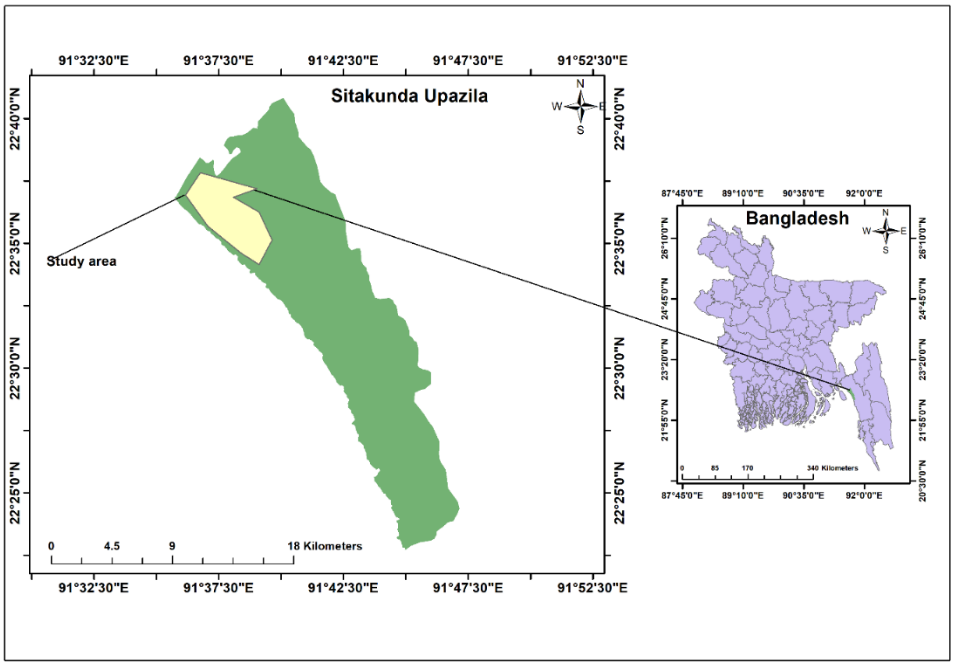

Figure 1. Study area under the Bogachattor forest beat in Sitakunda forest range under the Chattogram coastal forest division, Bangladesh.

2.2 Sampling and data collection

The total mangrove plantation under the Bogachattor forest beat up to 2016 was 546.12 ha (*pers. comm.*). The study considered the three frequently planted tree species, *Sonneratia apetala*, *Avicennia officinalis*, and *Excoecaria agallocha*. The official record of the Bogachattor forest beat helped identify these three frequently planted tree species. The age of each stand was 20 years, as per the plantation journal kept in the Bogachattor forest beat.

The study followed a random sampling technique to select the sample plots. A total of 30 square sample plots of 10m×10m size were studied. The total sampled area was 0.3 ha (3000 m^2); thus, the sampling intensity of this study came to 0.05%. Mohanraj *et al.* [29] covered a sampling intensity of 0.003231% for estimating carbon stock in the Kolli forest of Eastern Ghats, India. So, for carbon estimation, the sampling intensity of the present study is validated. For a convenient demarcation of the boundary of each plot, the study involved a nylon rope of 100 m in length.

The principal activity of this research was to analyze the tree aboveground biomass content (t ha^{-1}) to estimate carbon mass (t C ha^{-1}). It measured all the trees of more than 5 cm dbh for the sample plots. A structured data sheet was used to record dbh and total height data of the trees. dbh was measured using a diameter tape, while a Suunto Clinometer measured tree height. It recorded the center of the plot as the global coordinates (latitude, longitude) assisted by the GPS (Global Positioning System). The distribution of the sampled plots ranged from latitude 20°40'11.8" N to 22°40'25.8" N and longitude 91°33'09.2" E to 91°33'38.9" E. Bird-eye view of the study area shows the distribution of 30 sample plots in the following Figure 2.

Figure 2. Demarcated whole study area in the Bogachattor forest beat connecting the boundary waypoints under the Chattogram coastal forest division, Bangladesh.

2.3 Species composition, stand structure, and species diversity

The study recorded the height and dbh of all tree species, of which 26% trees were of the species *S. apetala*, 32% of *A. officinalis,* and 42% of *E. agallocha*. These species were identified using the reference of Siddiqi [8]. As only three species were present in the studied plots, no other methodology was adopted to identify the stand structure. Also, it determined the species-wise distribution of dbh and the total height class of these trees. For this, it put three cut-points in all dbh and total height values to make dbh and height classes based on equal percentile. Hence, it formed four height classes as ≤5.0, 5.1-10.0, 10.1-15.0, >15**,** and four dbh classes as ≤10.0, 10.1-15.0, 15.1-20.0, and >20.

2.4 Data analysis

The study applied the SPSS statistical software along with the use of Microsoft Excel to analyze the data. Firstly, it figured out tree species richness from the samples. Secondly, it analyzed the distribution of the diameter at breast height (dbh) and the total height class of the tree species. The allometric regression equation estimated the aboveground and belowground biomass in the trees. The standard biomass-carbon conversion factor converted the biomass to carbon. As the study did not find the species-specific allometric equations, the analysis used a general estimation model. The following allometric model described by Pearson *et al.* [30] estimated the aboveground biomass (AGB) and belowground biomass (BGB).

$$AGB,\ kg/tree = \exp(-2.289+2.649*lndbh - 0.021*lndbh^{2})$$

where *ln* is the natural logarithm.

$$BGB,\ kg/tree = \exp(-1.0587 + 0.8836*ln\mathrm{ABD})$$

where, *ln* is the natural logarithm.

AGB and BGB were converted into above and below ground carbon mass with a conversion factor of 0.5 [30]. The Mean Annual Increment (MAI) was calculated by dividing the total biomass and carbon mass by the age of the respective stand.

3. Results and Discussion

3.1 General findings of dbh and height of the tree

S. apetala is represented with the highest average dbh (20.04±0.93 cm), followed by *A. officinalis* (19.04±0.61 cm). Similarly, the average height (11.17±0.29) was also maximum for *S. apetala* (Figure 3). The dbh class >20 cm and 10.1-15.0 cm were maximum having 72.7% and 69.2%, respectively, in the height class 10.1-15.0 m of the tree species *S. apetala* (Table 1). The dbh class 10.1-15.0 cm and ≤10.0 cm were dominant in the height class 5.1- 10.0 m of the tree species *A. officinalis*, having 92.9% and 80.0%, respectively. Likewise, the dbh class 10.1-15.0 cm and ≤10.0 cm were dominant, having 88.2% and 81.0%, respectively, in the same height class of *E. agallocha*.

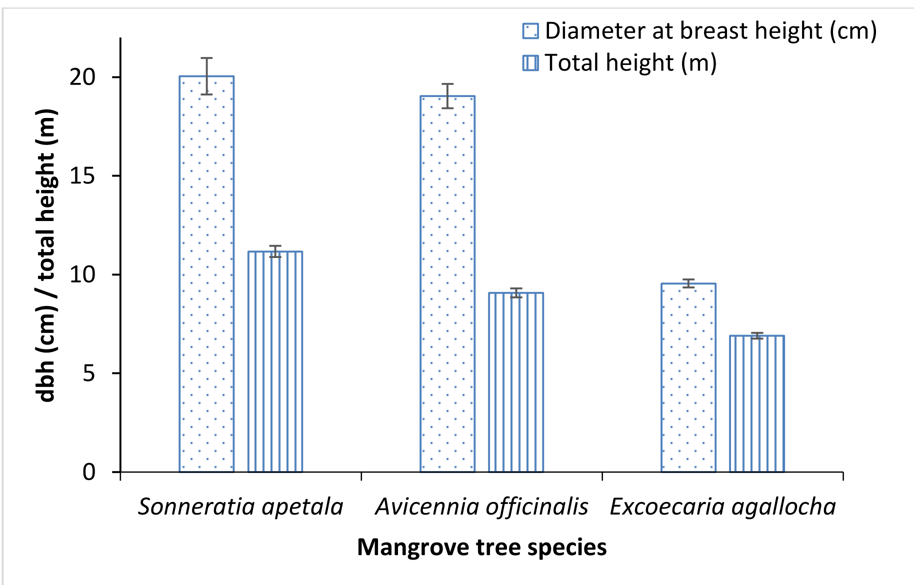

Figure 3. Average height and diameter of *A. officinalis*, *E. agallocha*, and *S. apetala* in the Bogachattor forest beat under the Chattogram coastal forest division, Bangladesh.

The dbh class >20 cm was minimum, having 6.8% in the height class >15 m of the *S. apetala*. Likewise, it noticed the least percentage (2.1%) of the same dbh class and the same height class of *A. officinalis*. For *E. agallocha*, the dbh class ≤10 cm had only 3.8% individuals in the height class 10.1-15.0 m.

Table 1. Height and dbh class distribution of coastal planted tree species in the Bogachattor forest beat under the Chattogram coastal forest division, Bangladesh.

Tree species and dbh class (cm)	**Height class (m) (%)**				
	≤5.0	**5.1-10.0**	**10.1-15.0**	**>15**	**Total**
Avicennia officinalis					
≤10	10.0	80.0	10.0	-	100
10.1-15	-	92.9	7.1	-	100
15.1-20	-	64.5	35.5	-	100
>20	-	47.9	50.0	2.1	100
Excoecaria agallocha					
≤10	15.2	81.0	3.8	-	100
10.1-15	-	88.2	11.8	-	100
15.1-20	-	50.0	50.0	-	100
>20	-	-	-	-	-
Sonneratia apetala					
≤10	15.4	53.8	30.8	-	100
10.1-15	7.7	23.1	69.2	-	100
15.1-20	-	33.3	50.0	16.7	100
>20	-	20.5	72.7	6.8	100

The mean dbh and total height in the *S. apetala* plantation were 20.04±0.93 cm and 11.17±0.29 m, respectively. These values for *A. officinalis* were 19.04±0.61 cm and 9.08±0.23 m, respectively. *E. agallocha* plantation revealed dbh 9.55±0.21 cm and a total height of 6.90±0.14 m, respectively, though the total number of individuals of this species was the highest (42%).

Though the number of individual trees of *S. apetala* was the lowest (26%), the highest value of mean dbh and total height were in the *S. apetala* plantation. The number of individual trees was the highest in *E. agallocha* plantation (42%), followed by *A. officinalis* plantation (32%). However, *E. agallocha* retained the lowest values of the mean dbh and total height.

A study by Estrada *et al.* [31] presents that the mean dbh and height of *Avicennia schaueriana* were 21.7 cm and 13.05 m, respectively, in a mangrove forest located in the biological reserve of Guaratiba, Septiba Bay, Brazil. In the Tanzania coastline, the mean dbh of *Avicennia marina*, *Sonneratia alba*, and *Rhizophora mucronate* were 17.6, 17.1, and 17.5 cm, respectively. In the case of the mean height of the species, the values were 9.6, 9.5, and 7.4, respectively [32].

The tree height and dbh relationships showed in the following Figure 4 indicated that there is a linear relationship between these two growth parameters. *A. officinalis* and *S. apetala* have a comparatively higher linear relationship than that's of *E. agallocha*. However, the coefficient of determination of the linear regression equations for height and dbh relationships showed that *A. officinalis* could explain only 29% of the variations in total height, whereas it is only 10% for *E. agallocha*. It hints that there is a scope of developing better-fitting models including other variables (i.e., wood density, site quality, etc.) to indicate the height-dbh relationships of the three species.

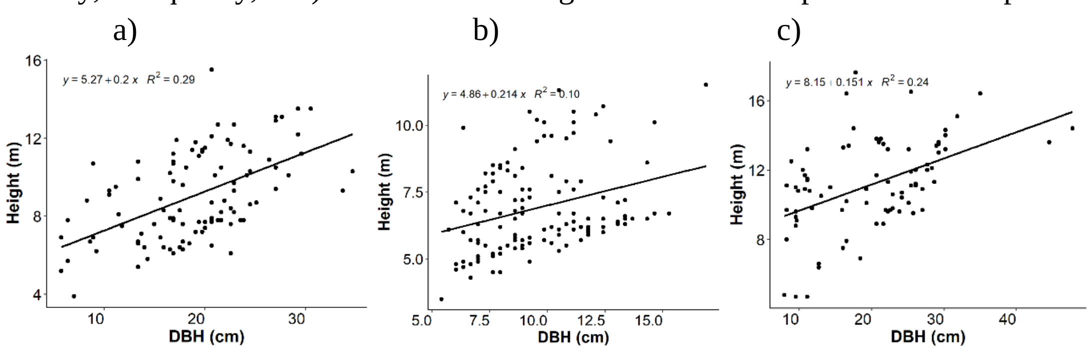

Figure 4. Height-Diameter relationship a) *A. officinalis*, b) *E. agallocha*, and c) *S. apetala* in the Bogachattor forest beat under the Chattogram coastal forest division, Bangladesh.

3.2 Tree-biomass growth and its carbon in the coastal afforestation

The aboveground, belowground, and total biomass density were 369.86±71.45 t ha^{-1}, 62.76±10.61 t ha^{-1}, and 432.61±82.02 t ha^{-1}, respectively, in the *S. apetala* plantation (Table 2). In the *A. officinalis* plantation, the aboveground, belowground, and total biomass density were 213.27±20.36, 37.89±3.36, and 251.15±23.71 t ha^{-1}, respectively. For the *E. agallocha* plantation, the aboveground, belowground, and total biomass density values were 48.38±4.17, 10.71±0.87, and 59.08±5.04 t ha^{-1}, respectively.

Table 2. Tree biomass growth and carbon in the Bogachattor forest beat under the Chattogram coastal forest division, Bangladesh.

Species	Total AGB (t ha^{-1})	Total BGB (t ha^{-1})	Total biomass (t ha^{-1})	Total biomass-carbon (t C ha^{-1})
Sonneratia apetala	369.86±71.45	62.76±10.61	432.61±82.02	216.31±41.01
Avicennia officinalis	213.27±20.36	37.89±3.36	251.15±23.71	125.58±11.85
Excoecaria agallocha	48.38±4.17	10.71±0.87	59.08±5.04	29.54±2.52

Note: AGB indicates Aboveground Biomass and BGB indicates Belowground Biomass.

As the mean dbh of *S. apetala* was the highest (20.04 ± 0.93 cm) followed by *A. officinalis* (19.04 ± 0.61 cm) and *E. agallocha* (9.55 ± 0.21), the aboveground, belowground, and total biomass density were also the highest in *S. apetala* followed by *A. officinalis* and *E. agallocha*.

Henry *et al.* [33] reported 98.37 t ha^{-1} aboveground biomass from the Sundarbans zone of Bangladesh, lower than the aboveground biomass of *A. apetala* and *A. officinalis*. It may be due to the differences in the sampling strategy and composition of forests between Sundarbans and the present study area. According to Steinke *et al.* [34], the mean aboveground living biomass of mangroves in the Mgeni estuary of South Africa was 94.49±7.83 t C ha^{-1}. Another study about the Sundarbans presents that the estimated total aboveground biomass of *Ceriops decandra* was 33.49 and 14.36 t C ha^{-1}, respectively [35]. From the above discussion, it can be said that the aboveground biomass, belowground biomass, and total biomass of the three species in the Bogachattor forest beat represent a reasonable stock level.

It is essential to quantify the mangrove carbon pools for formulating climate change mitigation strategies. For the biomass growth, carbon mass was also the highest, 216.31±41.01 t C ha^{-1}, in *S. apetala* plantation, followed by *A. officinalis*, 125.58±11.85 t Cha^{-1}, and *E. agallocha*, 29.54±2.52 t C ha^{-1}. The carbon density is much higher than that is of Henry et al. [33] reported from the Sundarbans zone (49.28 t C ha^{-1}), which may be due to the differences in the methods and forest structures. However, it indicates a higher potentiality of carbon sequestration by the coastal afforestation of Sitakunda, Chattogram. A study in Australia shows that the estimated aboveground biomass of mangrove species was 123 t C ha^{-1} [36], and another study in Brazil depicts that the estimated aboveground biomass of 296 mangrove trees was 2.92 t C ha^{-1} [37]. The above discussion shows a standard biomass-carbon stock in the mangrove trees in the Bogachattor forest beat.

A study in Vietnam shows the ecosystem carbon stock of Can Gio Mangrove Biospheres Reserve and Kien Vang Protection Forest, which were 889±111 t C ha^{-1} and 844±58 t C ha^{-1}, respectively [14]. The mean ecosystem carbon across the three Indonesian mangrove forests was 993.3 t C ha^{-1} [38]. The excessively higher concentration of carbon at the ecosystem base in Vietnam and Indonesia is due to the mostly higher accumulation of organic carbon in the forest soils and higher biomass growth in the forests [39].

Another study of Japan reports that the total biomass carbon stock in Manko Wetland, Okinawa Island, was 62 t C ha^{-1} [40]. Again, in a study, it is found that the forests of Bangladesh can sequestrate 92 t Cha^{-1} on an average [41]. In the case of the Sundarbans, the mean carbon density was 256.7±17 t C ha^{-1} [42]. According to Rahman et al. [43], *Heritiera fomes* (Sundri) was the most dominating forest type storing more ecosystem carbon of 360.1±22.71 t C ha^{-1} than any other type in the Sundarbans. As ecosystem carbon includes carbon of all the pools of the forests, it is higher than both biomass-carbon and soil-carbon separately [39].

3.3 Mean Annual Increment (MAI) in total biomass and its carbon

The calculated Mean Annual Increment (MAI) of biomass and its carbon was the highest, 21.63±4.10 t ha^{-1} y^{-1} and 10.82±2.05 t C $ha^{-1}y^{-1}$, respectively, in the *S. apetala* plantation, followed by 12.56±1.19 t ha^{-1} y^{-1} and 6.28±0.59 t C ha^{-1} y^{-1}, respectively in the plantation of *A. officinalis* (Figure 5). The biomass and its carbon MAI were the lowest in the *E. agallocha* plantation, 2.95±0.25 t ha^{-1} y^{-1}, and 1.48±0.13 t C ha^{-1} y^{-1}, respectively.

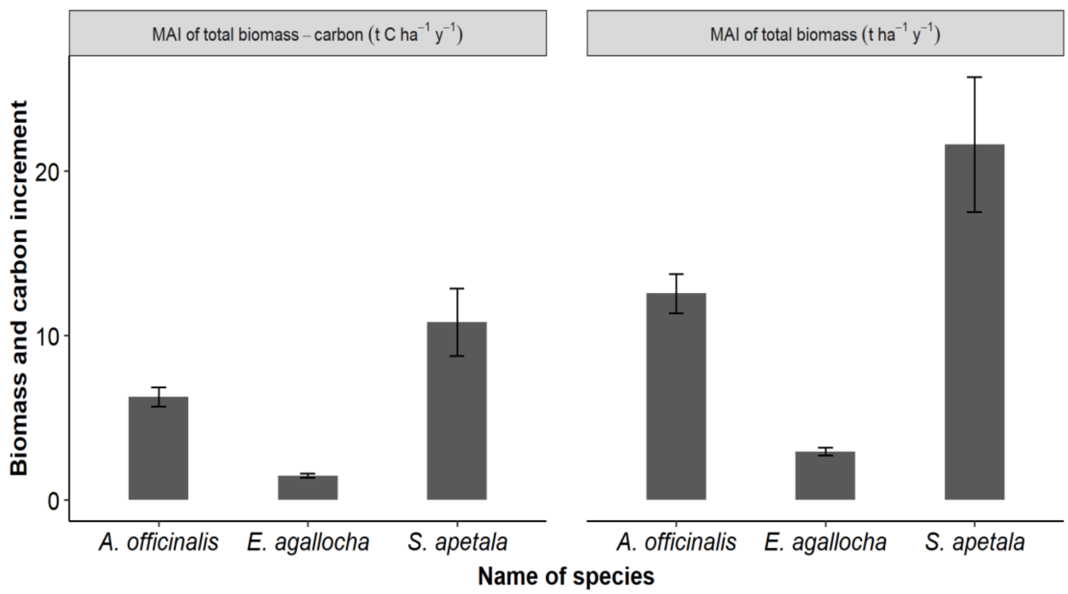

Figure 5. The Mean Annual Increment (MAI) of total biomass and biomass-carbon in the Bogachattor forest beat under the Chattogram coastal forest division, Bangladesh.

The mean dbh in *S. apetala* plantation (20.04±0.928 cm) is higher than *A. officinalis* (19.04±0.612) and *E. agallocha* (9.55±0.206) plantations. This is the reason for higher biomass and its carbon in *S. apetala* plantation (432.61±82.02 and

216.31±41.01, respectively) than the other two species. As a result, the *S. apetala* plantation reveals the highest values of MAI of biomass and its carbon, 21.63±4.10 and 10.82±2.05, respectively. The annual carbon sequestration by *A. officinalis* is much higher in the present study area than that is of an 8-year-old plantation (3.51±0.58 t C ha^{-1} y^{-1}) of the same species from Cox's Bazar. The carbon sequestration rate in *S. apetala* (3.91±0.1 t C ha^{-1} y^{-1}) planation from Cox's Bazar [26] is also lower than the same reported in the present study indicating the higher potentiality of the mangrove plants from coastal afforestation of Sitakunda, Chattogram.

A study of China shows that the accumulated average annual rate of total carbon storage at 4, 5, 8, and 10-year *S. apetala* plantation were 5.0, 7.9, 8.7, and 8.4 t C ha^{-1} y^{-1}, respectively [44]. Another study of the Dominican Republic published that the mean biomass increment of 23 plots in a 4700-ha mangrove forest was 9.7±1.0 t C ha^{-1} y^{-1} [45]. On the other hand, the MAI of biomass and its carbon were 8.56±0.24 and 3.84±0.11 t C ha^{-1} y^{-1}, respectively, in the *Casuarina equisetifolia* shelterbelt, Parki beach, Chattogram [46]. So, it can say that the MAI of biomass and its carbon found in the study for *S. apetala*, *A. officinalis,* and *E. agallocha* are at a reasonable level compared to other studies.

4. Conclusion

Diameter at breast height and height class distribution of mangrove tree species show *Sonneratia apetala* as a dominant tree species in the coastal plantation. *S. apetala* had the highest total biomass growth, 432.61±82.02 t ha^{-1}, with a mean annual increment of 21.63±4.10 t ha^{-1} y^{-1} among the three species. The species also had the highest carbon stock, 216.31±41.01 t C ha^{-1}, with the mean annual increment of 10.82±2.05 t C ha^{-1} y^{-1}. The total carbon mass in *S. apetala* stands reveals a high potential to mitigate climate change. The present study suggests the highest percentage of plantations with *S. apetala* trees. The study also shows a clear indication that *S. apetala*, *A. officinalis,* and *E. agallocha*-based afforestation can be an effective climate change adaptation measure in the Chittagong coastal belt of Bangladesh. The study exposes the potentiality of carbon sequestration in the mangrove afforestation sites in Chattogram of Bangladesh. The study can lead the policymakers, researchers, and administrators to reorient the coastal afforestation options to achieve the long-term carbon credits and mitigate climate change.

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