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Original Article

# Carbon concentration in the coastal afforestation sites of Cox's Bazar, Bangladesh

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## ABSTRACT

This study quantified carbon in tree biomass and soil in the coastal afforestation sites of Cox's Bazar, Bangladesh. It estimated that the total biomass density of *Avicennia alba, Avicennia officinalis, Casuarina equisetifolia,* and *Sonneratia apetala* were 225.81 ± 13.85, 56.07 ± 9.21, 320.39 ± 20.84 and 179.82 ± 4.69 tha$^{-1}$, respectively, with mean annual increment of 9.82 ± .60, 7.01 ± 1.15, 32.07 ± 1.63 and 7.82 ± .2 tha$^{-1}$, respectively. Furthermore, the total biomass carbon of *A. alba, A. officinalis, C. equisetifolia*, and *S. apetala* were 112.90 ± 6.92, 28.03 ± 4.61, 160.19 ± 10.42 and 89.91 ± 2.34 tCha$^{-1}$, respectively, with mean annual increment of 4.91 ± .30, 3.51 ± .58, 16.04 ± .81 and 3.91 ± .10 tCha-1yr$^{-1}$, respectively. The soil organic carbon stock was the highest in the *A. alba* plantation (12.45 ± .20 tCha$^{-1}$ at 10 cm depth and 37.33 ± .61 tCha$^{-1}$ at 30 cm depth). On the contrary, the soil carbon stock in the *C. equisetifolia* stands were the lowest at both soil depths (4.43 ± .20 at 10 cm depth and 13.30 ± .61 tCha$^{-1}$ at 30 cm depth). However, the total carbon, which includes that of the tree biomass and soil, was the highest at both soil depths in the *C. equisetifolia* stands (164.63 ± 10.58 tCha$^{-1}$ and 173.49 ± 10.90 tCha$^{-1}$), and the lowest in the A. officinalis stands. The present study concludes that *C. equisetifolia* stands have enormous potential to mitigate climate change in the coastal areas of Cox's Bazar, Bangladesh. The findings of the study will expedite the research and policymaking on climate change mitigation in Bangladesh.

*Keywords*: Aboveground biomass, belowground biomass, coastal plantation, soil organic carbon, tree species

## Introduction

Climate change is one of the significant environmental concerns of communities in the world in recent times, and this is because of the increasing concentration of $CO_2$ in the atmosphere which imposes global warming and, consequently, global climate change (Cox et al., 2000). Changes in temperature and precipitation under climate variation have a dangerous influence on hydrologic processes and availability of water resources (Islam & Sikka, 2010; Jordan, 2007). In the fifth assessment report (AR5), IPCC (2014) predicted that, by the end of the 21$^{st}$ century, the global mean surface temperature is likely to increase from .3°C to 1.7°C under a stringent mitigation scenario, and from 2.6°C to 4.8°C under a scenario of very high greenhouse gas emissions relative to the temperature rise between year 1986 and 2005. Coastal afforestation is one of the approaches for combating global climate change. Mangroves play a crucial role in carbon sequestration since mangrove forests are among the most carbon-rich biomes. The carbon pool in mangrove biomass ranges from 1.2×10$^{9}$ t C (Laffoley & Grimsditch, 2009) to 4.98×10$^{9}$ t C (Chmura et al., 2003). On average, mangroves contain 937 tCha$^{-1}$ (Alongi, 2012). In the Indo-Pacific region, it contains an average concentration of 1,023 tCha$^{-1}$ (Donato et al., 2011).

Soil is a good source of carbon in different forest pools. From a global perspective, at 1 m and 2 m depth, soil organic carbon was estimated as 1.5×10$^{12}$ tons and 2.5 × 10$^{12}$ tons, respectively (Petrokofsky et al., 2012). In Kashmir Himalaya, India, carbon stocks were estimated as 45.4-135.6, .08-1.18, .7-6.8, 1.1-1.4 and 39.1-91.4 tCha$^{-1}$ in tree, understory, deadwood, litter & soil, respectively (Dar & Sundarapandian, 2015). The concentration of soil organic carbon in East Timor, Southeast Norway, and agricultural land of Senegal was estimated as 230 tCha$^{-1}$, 3.34 × 10$^{11}$ tCha$^{-1,}$ & 11.3 tCha$^{-1}$, respectively (De Wit et al., 2006; Lasco & Cardinoza, 2007; Tschakert, 2004). Total organic carbon in the managed dense Shorea forest was predominant in Nepal, indicating an aboveground biomass carbon of 169 ± 26 tCha$^{-1}$, and a belowground biomass carbon of 50 ± 8 tCha$^{-1}$ (Shrestha & Singh, 2008). Miah et al., (2013) estimated an aboveground carbon density of 73.16 ± 2.04 tCha$^{-1}$, with mean annual increment of 3.85 ± .11 tCha$^{-1}$ yr$^{-1}$ for *Casuarina equisetifolia* plantation in the coastal area of Chittagong, Bangladesh. The total carbon carrying capacity and carbon sequestration potential

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of the existing forests in China were $1.987\times10^{10}$ and $1.386\times10^{10}$ tons, respectively (YingChun et al., 2014). In the natural forests of India, the total biomass estimated in *Shorea robusta* was 489 $tha^{-1}$, which includes a total biomass-carbon of 220.36 $tCha^{-1}$ (Lal and Singh, 2000).

Bangladesh Forest Department started the coastal plantation with mangrove species in 1966, with the intention of mitigating the disastrous effects of cyclones and storm surges (Das and Siddiqi, 1985; Siddiqi, 2001). Later, different forest divisions of coastal circle including those of Chittagong, Feni, and Cox's Bazar forest division carried out some large afforestation programs along the coastal belt under various development projects (Islam & Rahman, 2015). The blue carbon stock above and below ground in the Sundarbans mangrove was $3.624\times10^{7}$ tC and $5.495\times10^{7}$ tC, respectively (Chanda et al., 2016). Ahmed et al. (2017) estimated the rate of blue carbon sequestration in the Sundarbans mangrove as .50 to .61 million tons per year. Sundri (*Heritiera fomes*)-dominated forest types in the mangroves store more ecosystem carbon (360.1 ± 22.71 $tCha^{-1}$) than other vegetation types (Rahman et al., 2015b). The average soil and biomass carbon in *Aphanamixis polystachya* on the campus of University of Chittagong were 53.96 $tCha^{-1}$ and 239 $tCha^{-1}$, respectively (Miah et al., 2009). In Tankawati natural forest, total carbon stock was 283.80 $tCha^{-1}$ (Ullah & Al Amin, 2012), while Ullah et al. (2014) observed the highest amount of carbon stock (211.09 $tCha^{-1}$) in a 18-year-old *Acacia auriculiformis* plantation.

Based on literatures on carbon sequestration in the forests of Bangladesh, some studies were conducted at the southwestern regions and mangrove forests (Ahmed et al., 2017; Aysha et al., 2015; Chanda et al., 2016; Hossain et al., 2016b; Islam, 2016; Kamruzzaman et al., 2018; Mazumder et al., 2016; Rahman et al., 2015a); some were conducted in campus areas of different universities in Bangladesh (Akter et al., 2013; Hanif et al., 2015; Haque & Karmakar, 2009; Hossain & Banik, 2005; Miah et al., 2009); some were conducted on the hilly regions and watershed areas of Chittagong Division (Alamgir & Al Amin, 2007; Barua & Haque, 2013; Rahman et al., 2013; Shin et al., 2007; Ullah & Al Amin, 2012); some were conducted on Ganges-Brahmaputra basin and agro ecological zones (Saha et al., 2014; Uddin, 2016); some were conducted in natural forests and wildlife sanctuary (Islam et al., 2017; Sohel et al., 2015; Ullah et al., 2014); and some were conducted on aboveground carbon stock in several districts in Bangladesh (Dey et al., 2014; Jaman et al., 2016). However, no study was conducted on carbon sequestration at the coastal afforestation sites in Cox's Bazar, Bangladesh. In this regard, there is a research question on the concentration of carbon in tree biomass and soils in the coastal afforestation sites of Cox's Bazar. Based on this research question, the present study hypothesized that the coastal plantation of Cox's Bazar had carbon sequestered in both tree biomass and soils, and are not much differentiated than that of other coastal plantations in Bangladesh. To answer the is research questions, an empirical study undertook the specific objectives of identifying the structure and growing stock of coastal afforestation, and quantifying the tree and soil carbon sequestration in the coastal afforestation sites of Cox's Bazar, Bangladesh. Therefore, this study will enrich the knowledge pool of carbon estimation of coastal afforestation in Cox's Bazar, Bangladesh.

## Method

This study was conducted in the coastal afforestation sites of Cox's Bazar, Bangladesh. It studied a forest beat under the Chittagong coastal forest division in order to ascertain the carbon stock of the existing coastal plantation in Cox's Bazar. The study sampled and collected data from September 2017 to December 2018.

### Study Area

The study site was in the territory of Teknaf forest range under the Divisional Forest office of Cox's Bazar (South), Bangladesh. However, the coastal afforestation sites under this forest range are functionally under the Chittagong coastal forest division. Teknaf Upazila is located at the trans-boundary of Bangladesh and Myanmar, occupying an area of about 388.68 $km^2$ between latitude 21°10′ N and 20°40′ N, and longitude 92°05′ E and 92°25′ E (BBS, 2012). It is among the most extended sandy beach ecosystems (80 km) in the world. The western coast of Teknaf is sandy, while non-calcareous alluvium is the dominant soil type (Chowdhury et al., 2011).

The Teknaf peninsula is characterized by a subtropical climate, with temperatures of 15°C and 33°C during winter (January) and summer (May), respectively. There is frequent heavy rainfall of approximately 4,000 mm per year. However, the rainfall varies widely throughout the year (Moslehuddin et al., 2018).

The tidal floodplain in the Teknaf peninsula runs from north to south and covers 6,838 ha of land. It is located between the hills and the Naf river. The area consists of broad, high and low ridges, and depressions. During rainy season, most of the areas become mildly inundated with rainwater and occasionally suffer flash floods during heavy rainfall (Moslehuddin et al., 2018). In the Teknaf forest range under Cox's Bazar (South) Forest Division, the Chittagong coastal forest division carried out an afforestation program through the mangrove, non-mangrove, strip, and *Nypa fruticans* plantation. In total, the division implemented 1,837.7 ha mangrove, 140.00 ha non-mangrove, and 62.00 km strip and *Nypa* species plantation up to 2016 in the Teknaf forest range of Cox's Bazar, Bangladesh (*pers. comm*)[1].

A view reflecting the location of the study area in Teknaf forest beat under Cox's Bazar (South) forest division is shown in Figure 1.

### Sampling and Data Collection

The study adopted a random sampling technique to select 80 sampling plots in the study area. It adopted a non-destructive data collection method. The size of each plot was 10 m×10 m. All the plots were square. The tree species richness in the repre-

[1] Personal communication with the office of Chittagong coastal forest division, Chittagong on 04/06/2018

sentative samples were analyzed first. The total height and diameter at breast height (DBH) were carefully measured in all the plots. A diameter tape was to measure the DBH, while Shunto Clinometer was used to measure the total height of the trees. A pre-trained forestry professional data crew utilized these instruments in collecting data from the field. The global coordinates (latitude and longitude) of the plots were recorded using the Global Positioning System (GPS). For further monitoring of the same plot, the center coordinates of the plots were set in the system of proximity alarm of the GPS. The location points of 80 plots were recorded in the datasheet.

**Collection of Primary Data**

The 80 plots were measured and recorded in a structured datasheet. The diameter at breast height (DBH) and the total height of the trees were measured. Four (4) frequently planted tree species including *Avicennia alba* (Moricha Baen), *Avicennia officinalis* (Baen), *Casuarina equisetifolia* (Jhaw) and *Sonneratia apetala* (Keora) were studied. From the plantation journals kept in the coastal afforestation division in Chittagong, the frequently planted tree species were recorded with their age of plantation. The aforementioned tree species share more than 80% of the total plantation established in the coastal areas of Teknaf forest range under Chittagong Coastal forest division, Bangladesh. In all the plots, trees with DBH ≥5 cm were measured. The plantation plots in the study area varied by the ages of the stands. Some of the *C. equisetifolia* plantation plots were 11 years old, while some were nine years old. *A. alba*, *A. officinalis*, and *S. apetala* plantation plots were 23, 8, and 23 years old, respectively. The tree species above were monocultured in separate stands. The replication of sampling plots was 20 times for each specie. However, this was ten times of each age of the stands for *C. equisetifolia*.

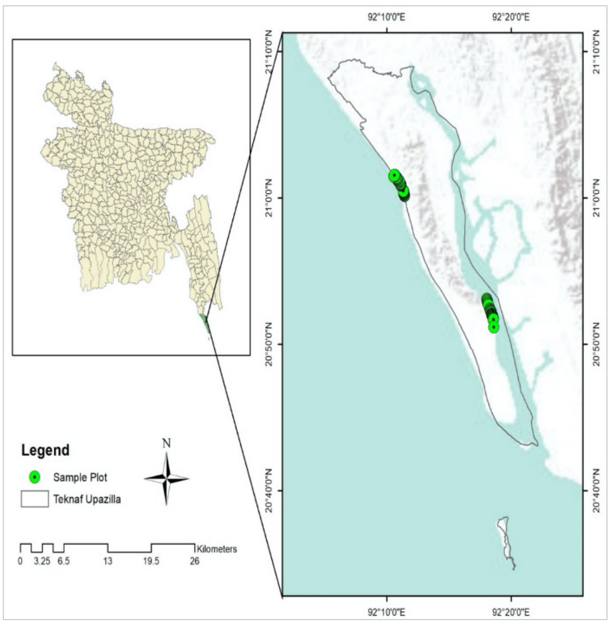


Figure 1
*Teknaf Forest Beat Under Cox's Bazar (South) Forest Division, Bangladesh*

For the soil sampling, fixed volume metallic soil core was used to measure the bulk density and organic carbon. To estimate the carbon contents in soils of the afforestation sites, soil samples were collected from all the selected plots. Under each of the vegetation plots, three soil samples were collected up to 10 cm and 30 cm soil-depth randomly. After collecting the three soil samples at both depths, one aggregated compound sample was formed for each of the depths. Two aggregated soil samples were considered for both 10 cm and 30 cm soil-depth for each of the plantation plots, totaling up to 160 soil samples (80 x 2).

**Data Analysis**

Allometric regression equation was used to measure the aboveground and belowground tree biomasss. The biomass was then converted to carbon using the standard biomass-carbon conversion factor of 0.5 (Pearson et al., 2005). Data was analyzed with IBM SPSS Statistics, version 24, and MS Excel 2016. Data was first input into the MS Excel and then exported to the IBM SPSS Statistics for analysis.

**Structure and Growing Stock of Coastal Afforestation**

This study determined the species-wise distribution of DBH and total height class of the trees. Two cut points was used for all values to ensure that the DBH and height class are on equal percentile, with a width of 33.33%. Therefore, the three height classes were as ≤10.30, 10.31-15.70, and ≥15.71 m, while the three DBH classes were ≤17.19, 17.20-20.69, and ≥20.70 cm. The total biomass of each species was divided by the age of the stands in order to ascertain the mean annual increment (MAI) and, consequently, the carbon increment.

**Determination of Tree Biomass Carbon Concentration**

Species-specific allometric equations were not generated for this study during the data analysis. However, a general equation was adopted. The following allometric model described by Pearson et al. (2005) was used to estimate the aboveground biomass density (ABD).

$$\text{Biomass, kg/tree} = \exp\left[-2.289 + 2.649 \times \ln(dbh) - .021 \times \ln(dbh)^2\right]$$

where *ln* is the natural logarithm.

The following model described by Pearson et al. (2005) estimated the belowground biomass density (BBD).

$$\text{BBD, kg/tree} = \exp(-1.0587 + .8836 \times \ln \text{ABD})$$

where *ln* is the natural logarithm.

The biomass, ABD and BBD were converted into carbon, ACD (aboveground carbon density), and BCD (belowground carbon density) using the standard biomass-carbon conversion factor.

**Determination of Organic Carbon in Soil**

**Soil preparation and analysis**

Soil samples were collected with a metallic core of known volume, and were weighed in the field using the standard weighing scale for measuring bulk density. The organic carbon measurement in the samples was then conducted in the soil laboratory. Wet oxidation method was used for the determination of the soil organic carbon.

To measure the soil organic carbon using the wet oxidation method, the following equation described by McLeod (1973) was applied:

$OC\% = .003g \times N \times 10ml \times (1- T/S) \times 100 \div ODW$
$= 3(1- T/S) \div ODW$
Where N= Normality of $K_2Cr_2O_7$ solution
T=Volume of $FeSO_4$ used in sample titration (mL)
S=Volume of $FeSO_4$ used in blank titration (mL)
ODW=Oven-dry sample weight (g)
$OM\%=10\ 1(S\div B) \times 0.67$
Where S=Sample titration
B=Blank titration

This method is also referred to as Walkley-Black method (Walkley & Black, 1934).

**Calculation of soil carbon**
To estimate soil organic carbon, the following models described by Pearson et al. (2005) were applied:

Bulk density ($gm/cm^3$)=mass (gm)/core volume ($cm^3$)
C ($tha^{-1}$)=((soil bulk density ($gm/cm^3$) × soil depth (cm)) × C ×100

Note: C is expressed as a decimal fraction; for instance, 2.2% is expressed as .022 in the equation; bulk density is expressed as $gm/cm^3$

## Results

**Structural Distribution of the Tree Species**
This study recorded the total height and diameter at breast height (DBH) of 770 trees, out of which 30.65% trees was *Avicennia alba*, 3.25% was *Avicennia officinalis*, 61.82% was *Casuarina equisetifolia*, and 4.28% was *Sonneratia apetala*. The species-wise distribution of height and DBH classes of the tree species are summarized in Table 1.

All the tree species of *A. alba* in the DBH class of ≤17.19 cm falls within the height class of ≤10.30 m. The height class of ≤10.30 m was dominant in all the DBH classes of *A. alba*, with 100%, 97.9%, and 65.3% in the DBH class of ≤17.19 cm, 17.20–20.69 cm and ≥20.70 cm, respectively. The DBH class of ≥20.70 cm was the highest, with 65.3% and 34.7% in the height class of ≤10.30 m and 10.31-15.70 m, respectively. No specie of *A. alba* falls within the height class of ≥15.71 m.

For the *A. officinalis*, all the trees fall in the DBH class of ≤17.19 cm, and the height class of ≤10.30 m. The plantation sites of *A. officinalis* were young, having the age of eight (8) years. For the *C. equisetifolia* species, the DBH class of ≤17.19 cm was dominant in the height class of 10.31-15.70 m with 53.0%. The DBH class of 17.20-20.69 cm and ≥20.70 cm were dominant in the height class of ≥15.71 m, with 61.5% and 56.9%, respectively. The DBH class of 17.20-20.69 cm and ≥20.70 cm had no tree specie in the height class of ≤10.30 m, but had 38.5% and 43.1% tree species in the height class of 10.31-15.70 m, respectively, for the *C. equisetifolia* species.

The DBH class of ≤17.19 cm and 17.20-20.69 cm were dominant in the height class of ≤10.30 m for the *Sonneratia apetala* species, with 100% and 86.7%, respectively. Foe the *Sonneratia apetala* species, DBH class of ≥20.70 cm was maximum in the height class of 10.31-15.70 m followed by the height class of ≤10.30 m, with 60% and 40%, respectively. The DBH class of ≤17.19 cm was dominant in the height class of ≤10.30 m, with 100% for *A. alba*, *A. officinalis,* and *S. apetala* species. However, for *C. equisetifolia* tree species, the height and DBH class had only 7.9% trees. For *A. alba* and *S. apetala* tree species, the DBH class of 17.20-20.69 cm had very few trees, with 2.1% and 13.3%, respectively, in the height class of 10.31-15.70 m.

The highest value of the mean DBH was in the *A. alba* species (20.20 ± 0.33 cm), while the highest value of the total height was in the *C. equisetifolia* species (15.33 ± 0.10 m) (Figure 2).

**Tree Biomass Growth and Its Carbon in the Coastal Afforestation**
The aboveground biomass density, belowground biomass density, and total biomass density in *A. alba* were 191 ± 11.91 $tha^{-1}$, 34.11 ± 1.94 $tha^{-1}$, and 225.81 ± 13.85 $tha^{-1}$, respectively (Table 2). In the *A. officinalis* stands, the aboveground, belowground, and total biomass density were 46.14 ± 7.64, 9.93 ± 1.57, and 56.07 ± 9.21 $tha^{-1}$, respectively. For *C. equisetifolia*, the values of aboveground, belowground, and total biomass density were 271.18 ± 17.90, 49.21 ± 2.94, and 320.39 ± 20.84 $tha^{-1}$, respectively. For *S. apetala*, the aboveground, belowground, and total biomass density were 151.39 ± 4.0, 28.43 ± .70, and 179.82 ± 4.69 $tha^{-1}$, respectively.

In the present study, the *A. alba* stands had the highest mean DBH followed by *C. equisetifolia*, *S. apetala,* and *A. officinalis*, but the aboveground, belowground and total biomass density were the highest in *C. equisetifolia* followed by *A. alba*, *S. apetala,* and *A. officinalis*. The number of *C. equisetifolia* stands was the highest in the study area (61.82%) and, therefore, the total biomass density was the highest for this species.

In relation to the biomass growth, the biomass-carbon was also the highest in *C. equisetifolia* (160.19 ± 10.42 $tCha^{-1}$) followed by *A. alba* (112.90 ± 6.92 $tCha^{-1}$), *S. apetala* (89.91 ± 2.34 $tCha^{-1}$) and *A. officinalis* (28.03 ± 4.61 $tCha^{-1}$) (Table 2).

**Mean Annual Increment (MAI) in Total Biomass and Its Carbon**
Since the stand age of the plantation plots are known, this study determined the Mean Annual Increment (MAI) of biomass and its carbon. The calculated MAI of biomass and its carbon was the highest (32.07 ± 1.63 $tha^{-1}yr^{-1}$ and 16.04 ± .81 $tCha^{-1}yr^{-1}$, respectively) in *C. equisetifolia* stands followed by 9.82 ± .60 $tha^{-1}yr^{-1}$ and 4.91 ± .30 $tCha^{-1}yr^{-1}$, respectively, in *A. alba* stands (Table 3). The MAI of

Table 1
*Height and Diameter at Breast Height (DBH) Class Distribution of the Tree Species in the Coastal Afforestation Sites of Cox's Bazar, Bangladesh*

| | | | Height class (m) (%) | | | |
|---|---|---|---|---|---|---|
| | | | ≤10.30 | 10.31 - 15.70 | 15.71+ | Total |
| *Avicennia alba* (23 years old) | DBH class (cm) | ≤17.19 | 100 | .0 | .0 | 100.0 |
| | | 17.20 - 20.69 | 97.9 | 2.1 | .0 | 100.0 |
| | | 20.70+ | 65.3 | 34.7 | .0 | 100.0 |
| *Avicennia officinalis* (8 years old) | DBH class (cm) | ≤17.19 | 100 | .0 | .0 | 100.0 |
| | | 17.20 - 20.69 | .0 | .0 | .0 | .0 |
| | | 20.70+ | .0 | .0 | .0 | .0 |
| *Casuarina equisetifolia* (9 and 11 years old) | DBH class (cm) | ≤17.19 | 7.9 | 53.0 | 39.0 | 100.0 |
| | | 17.20 - 20.69 | .0 | 38.5 | 61.5 | 100.0 |
| | | 20.70+ | .0 | 43.1 | 56.9 | 100.0 |
| *Sonneratia apetala* (23 years old) | DBH class (cm) | ≤17.19 | 100 | .0 | .0 | 100.0 |
| | | 17.20 - 20.69 | 86.7 | 13.3 | .0 | 100.0 |
| | | 20.70+ | 40.0 | 60.0 | .0 | 100.0 |

*Note*: Figures in the cell indicates the percentage value

Table 2
*Tree biomass growth and its carbon in the coastal afforestation sites of Cox's Bazar, Bangladesh*

| Species | ABD ($tha^{-1}$) | BBD ($tha^{-1}$) | Total biomass ($tha^{-1}$) | Total biomass carbon ($tCha^{-1}$) |
|---|---|---|---|---|
| *Avicennia alba* | 191 ± 11.91 | 34.11 ± 1.94 | 225.81 ± 13.85 | 112.90 ± 6.92 |
| *Avicennia officinalis* | 46.14 ± 7.64 | 9.93 ± 1.57 | 56.07 ± 9.21 | 28.03 ± 4.61 |
| *Casuarina equisetifolia* | 271.18 ± 17.90 | 49.21 ± 2.94 | 320.39 ± 20.84 | 160.19 ± 10.42 |
| *Sonneratia apetala* | 151.39 ± 4.0 | 28.43 ± .70 | 179.82 ± 4.69 | 89.91 ± 2.34 |

*Note*. ABD = Aboveground biomass density; BBD = Belowground biomass density

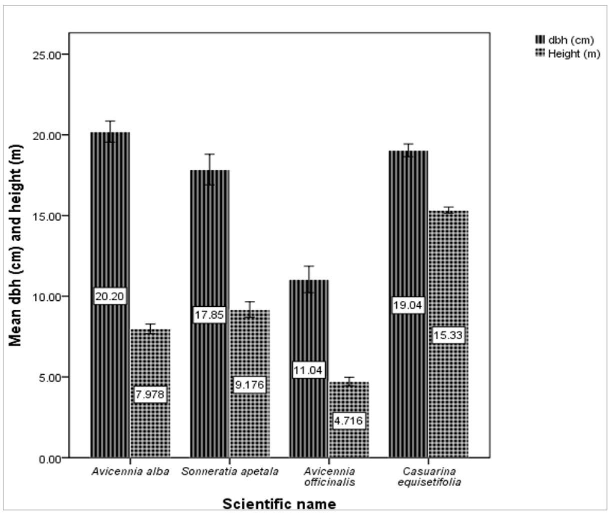


Figure 2
*Mean Diameter at Breast Height (DBH) and Height Observed in the Coastal Plantation of Cox's Bazar, Bangladesh*

biomass and its carbon were the lowest in the *A. officinalis* stands (7.01 ± 1.15 $tha^{-1}yr^{-1}$ and 3.51 ± .58 $tCha^{-1}yr^{-1}$, respectively).

There were a total of 476 trees of *C. equisetifolia* in the sampled plots. The mean DBH of the *Casuarina equisetifolia* species was 19.04 ± .33 cm, which is the second largest in the study area. The total biomass and its carbon were the highest in the *C. equisetifolia* species (320.39 ± 20.84 $tha^{-1}$ and 160.19 ± 10.42 $tCha^{-1}$, respectively) than the other three species in the study area. Consequently, the *C. equisetifolia* species showed the highest values of MAI of biomass and its carbon (32.07 ± 1.63 $tha^{-1}yr^{-1}$ and 16.04 ± .81 $tCha^{-1}yr^{-1}$, respectively).

**Soil Organic Carbon in the Coastal Afforestation**
Soil organic carbon percentage was the highest in *A. alba* stands (.77 ± .01%) followed by *S. apetala* stands (.71 ± .02%), *A. officinalis* stands (.67 ± .05%), and *C. equisetifolia* stands (.28 ± .01%) (Table 4).

Based on the soil organic carbon percentage and the soil depth measurement, the organic carbon was the highest at 10 cm soil depth (12.45 ± .20 $tCha^{-1}$) and 30 cm soil depth (37.33 ± .61 $tCha^{-1}$)

in *A. alba*, followed by the 10 cm (11.87 ± .32 $tCha^{-1}$) and 30 cm soil depth (35.61 ± .97 $tCha^{-1}$) in *S. apetala* stands (Table 4). The lowest quantity of organic carbon was 4.43 ± .20 $tCha^{-1}$ and 13.30 ± .61 $tCha^{-1}$ at 10 cm and 30 cm soil depth, respectively, in the *C. equisetifolia* stands.

**Total Biomass-Carbon and Soil Organic Carbon Concentration**

Total biomass and soil organic carbon at 10 cm and 30 cm soil depth was the highest (164.63 ± 10.58 $tCha^{-1}$, 173.49 ± 10.90 $tCha^{-1}$, respectively) in the *C. equisetifolia* stands (Table 5). Although soil carbon stock was the lowest in *C. equisetifolia* stands in both soil depths, the highest biomass growth consequently yielded the highest total carbon concentration per hectare.

Table 3
*The Mean Annual Increment (MAI) of Total Biomass and Biomass-Carbon in the Coastal Afforestation Sites of Cox's Bazar, Bangladesh*

| Species | MAI of total biomass $tha^{-1}yr^{-1}$ | MAI of total biomass carbon $tC\ ha^{-1}yr^{-1}$ |
|---|---|---|
| *Avicennia alba* | 9.82 ± .60 | 4.91 ± .30 |
| *Avicennia officinalis* | 7.01 ± 1.15 | 3.51 ± .58 |
| *Casuarina equisetifolia* | 32.07 ± 1.63 | 16.04 ± .81 |
| *Sonneratia apetala* | 7.82 ± .2 | 3.91 ± .10 |

Table 4
*Soil Organic Carbon in the Coastal Afforestation Sites of Cox's Bazar, Bangladesh*

| Species name | Soil organic carbon (%) | Soil carbon ($tC\ ha^{-1}$) at 0-10 cm soil depth | Soil carbon ($tC\ ha^{-1}$) at 0-30 cm soil depth |
|---|---|---|---|
| *Avicennia alba* | .77 ± .01 | 12.45 ± .20 | 37.33 ± .61 |
| *Avicennia officinalis* | .67 ± .05 | 11.15 ± .63 | 33.45 ± 1.90 |
| *Casuarina equisetifolia* | .28 ± .01 | 4.43 ± .20 | 13.30 ± .61 |
| *Sonneratia apetala* | .71 ± .02 | 11.87 ± .32 | 35.61 ± .97 |

Table 5
*Total Tree Biomass and Soil Organic Carbon in the Coastal Afforestation Sites of Cox's Bazar, Bangladesh*

| Species | Total biomass and soil carbon at 10 cm depth ($tCha^{-1}$) | Total biomass and soil carbon at 30 cm depth ($tCha^{-1}$) |
|---|---|---|
| *Avicennia alba* | 125.35 ± 6.89 | 150.23 ± 6.83 |
| *Avicennia officinalis* | 39.18 ± 5.11 | 61.48 ± 6.18 |
| *Casuarina equisetifolia* | 164.63 ± 10.58 | 173.49 ± 10.90 |
| *Sonneratia apetala* | 101.78 ± 2.34 | 125.52 ± 2.45 |

Total biomass and soil organic carbon in the *A. alba* and *S. apetala* stands in the coastal afforestation sites in Cox's Bazar was second and third highest at both 10 cm and 30 cm soil depths. Total carbon in the *A. officinalis* stands was the lowest, with 39.18 ± 5.11 $tCha^{-1}$ and 61.48 ± 6.18 $tCha^{-1}$ at 10 cm and 30 cm soil depths, respectively.

## Discussion, and Conclusion and Recommendations

The mean DBH and total height in the *S. apetala* stands were 17.85 ± .47 cm and 9.18 ± .24 m, respectively. In *A. officinalis* stands, the mean DBH and total height were 11.04 ± .41 cm and 4.72 ± .13 m, respectively, since they were the youngest (8 years old). Although *A. alba* and *S. apetala* stands were the oldest plantations (23 years old), the total height was the highest in *C. equisetifolia* stands aged 9 and 11 years. However, the DBH value was the highest in *A. alba* stands, while the height was the highest in the *S. apetala* stands. Estrada et al. (2013) reported a mean DBH and height of 21.7 ± 2.4 cm and 13.05 ± .85 m, respectively, for *A. schaueriana* in a mangrove forest located in the biological reserve of Guaratiba, Sepetiba Bay, Brazil.

*S. apetala* showed a diameter growth ranging from 10.3 to 26.5 cm, with an average value of 15.64 cm at Bogachottor beat in Sitakunda range[2] and Domkhali beat of Mireshsarai range[3] (Haque et al., 2000). Uddin and Hossain (2013) reported that 27 years old *S. apetala* attained a DBH and height growth of 21 cm and 16.5 m, respectively, in Ochkhali beat, and a DBH and height growth of 24.5 cm and 18.5 m, respectively, in Dalchar beat of Nolchira range of Hatiya island, Bangladesh, and this is in consonant with the present study.

*A. officinalis* plantation of 20-29 years attained a DBH and height range of 13.0-21.5 cm and 7.4-10.2 m, respectively, in three forest beats of Mireshsarai coastal forest (Uddin & Hossain, 2013), and this is very close to the result obtained for the 23-year-old plantation having the DBH and height of 11.04 ± .41 cm and 4.72 ± .13 m, respectively. According to Hossain et al. (2016a), the average DBH and height of a 16-year-old *Casuarina* plantation at Kosturaghat beat of Cox's Bazar, Bangladesh was 19.6 cm and 19.2 m, and this seems relevant to the findings (DBH=19.04 ± .20 cm, height=15.33 ± .10 m) of the present study.

Miah et al. (2013) reported an aboveground biomass density of 162.58 ± 4.52 $tha^{-1}$ in the *C. equisetifolia* shelterbelt on the Chittagong coast of Bangladesh. In this study, the aboveground biomass for the same specie was 271.18 ± 17.90 $tha^{-1}$ in coastal zones of Cox's Bazar. The total aboveground biomass for *A. alba, S. apetala, A. officinalis,* and *C. equisetifolia* were 191 ± 11.91, 151.39 ± 4.0, 46.14 ± 7.64 and 271.18 ± 17.90 $tha^{-1}$, respectively. According to Steinke et al. (1995), the mean aboveground living biomass of mangroves in the Mgeni estuary of South Africa was 94.49 ± 7.83 $tha^{-1}$.

A study in Japan reports that the total biomass-carbon stock in Manko wetland, Okinawa island was 71.17 $tCha^{-1}$ (Hoque et

[2] Sitakunda range is one of the coastal forest ranges under the Chittagong coastal forest division, Bangladesh.
[3] Mireshsarai range is one of the coastal forest ranges under the Chittagong coastal forest division, Bangladesh.

al., 2011). Miah et al. (2013) reported the aboveground carbon density of 73.16 ± 2.04 $tCha^{-1}$ in *C. equisetifolia* shelterbelt in the coastal zones of Bangladesh. This study reveals that the total carbon in *C. equisetifolia* stands in the coastal afforestation sites of Cox's Bazar was 160.19 ± 10.42 $tCha^{-1}$. In the case of the Sundarbans, the mean carbon density was 256.7 ± 17 $tCha^{-1}$ (Ahmed and Iqbal, 2011). According to Rahman et al. (2015b), Sundri (*Heritiera fomes*)-dominated forest types stored more ecosystem carbon (360.1 ± 22.71 $tCha^{-1}$) than the other vegetation types. Therefore, it can opined from the foregoing discussion that the quantity of total carbon in the Teknaf forest beat under the Teknaf forest range in Cox's Bazar forest division reveals a standard level compared to other sites.

The mean annual increment of biomass and its carbon were 8.56 ± .24 $tha^{-1}yr^{-1}$ and 3.84 ± .11 $tCha^{-1}yr^{-1}$, respectively, in the *C. equisetifolia* shelterbelt, Parki Beach, Chittagong (Miah et al., 2013). A study in China shows that the accumulated average annual rate of total carbon storage of 4, 5, 8, and 10 years old *S. apetala* plantation were 5.0, 7.9, 8.7, and 8.4 $tCha^{-1}$ $yr^{-1}$, respectively (Ren et al., 2010). Thus, it can be said that the MAI of biomass and its carbon reported in this study for *A. alba, A. officinalis*, *C. equisetifolia,* and *S. apetala* reveals a right level compared to other studies.

Shaifullah et al. (2008) conducted a study in Telir Char, Laxmipur coast of Bangladesh. The recorded soil organic carbon contents in soil surface at inland, middle part, and sea-side of Telir Char plantation at 0-10 cm soil depth were .80%, .73%, and .49%, respectively. In another study, conducted on a 12-17 years old *S. apetala* at Char Alim and Char Piya in Hatiya of Noakhali district, Shaifullah et al. (2009) reported soil organic carbon contents in surface soil at inland, middle part and seaside of Char Alim plantation were 2.41%, 1.88%, and 1.51%, respectively, at 0-10 cm soil depth. The corresponding values in Char Piya coastal plantation were 2.25%, 2.09%, and 2.20%, respectively. The range of soil organic carbon in Char Alim and Char Piya is 1.51-2.41% and 2.09-2.25%, respectively. In this study, the percentage range of organic carbon in the study area is .28-.77%. The range of soil carbon stock in the bottom, middle, and top slope in Chittagong hilly region was 89-117 $tCha^{-1}$, 79-116 $tCha^{-1}$, and 71-100 $tCha^{-1}$, respectively (Miah et al., 2011).

Diameter at breast height (DBH) and height class distribution of tree species reveals *Casuarina equisetifolia* as the dominant tree species in the study area. *C. equisetifolia* had the highest total biomass growth and the highest mean annual increment among the four species. This specie also had the highest carbon stock (160.19 ± 10.42 $tCha^{-1}$), with the mean annual increment of 16.04 ± .81 $tCha^{-1}yr^{-1}$. Soil organic carbon concentration depends on the age of that stand, biomass, sedimentation, and tidal gradient of that forest. The soil carbon was the highest both at 10 cm and 30 cm soil depths for *Avicennia alba*. In this study, the total carbon concentration, including the biomass and soils at different depths, was the highest in the *C. equisetifolia,* indicating a high potential to mitigate climate change. The present study suggests the highest percentage for future plantation of *C. equisetifolia* trees in the coastal areas in Cox's Bazar, Bangladesh. The study shows a clear indication that, *A. alba*, *C. equisetifolia* and *S. apetala* based coastal afforestation can act as a climate change adaptation measure together with the climate change mitigation in the Cox's Bazar coastal belt of Bangladesh.

The study area is still free from the Rohingya refugee impacts. The study recommends the improvement of the degraded forest habitat, and compensation for the forest areas lost beneath the camps' footprint. The proposed actions include assistance to community/social forestry, reforestation, artificial natural regeneration of shrub-dominated areas, afforestation along the coastal line, and agroforestry in the village forests. These actions will keep the coastal plantation untouched. From this present study, it is clearly imperative to use the *A. alba*, *C. equisetifolia* and *S. apetala* tree species for coastal plantation.

This study shows the potentiality of the carbon sequestration in the coastal afforestation sites of Bangladesh. However, the study concludes that biomass growth and carbon concentration in the coastal plantations in the Cox's Bazar, Bangladesh does not show any remarkable differentiation than the other sites of coastal areas under Chittagong coastal forest division of Bangladesh. This espouses the hypothesis of this study. The study can spur the policymakers, researchers, and administrators to reorient the coastal afforestation options in order to achieve long term carbon credits, as well as to mitigate and adapt to climate change.

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