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CARBON STOCK OF DIFFERENT PARTS OF MAJOR PLANT SPECIES OF THREE ECOLOGICAL ZONES OF BANGLADESH SUNDARBANS

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Abstract

The biomass and carbon sequestration by different parts namely leaf, stem and roots of major dominant plant species of different quadrats established in three ecological zones of Bangladesh Sundarban Mangrove Forests (SMF) were determined. A visit was done during 28 March to 1 April 2016 covering the oligohaline, mesohaline and polyhaline zones of SMF. Plant parts (stem, branch and leaf) of major plant species were collected from 16 quadrats of different locations. The major plant species were selected on the basis of abundance (number). Aboveground biomass (AGB) was estimated as the product of tree volume and wood density. Below ground biomass (BGB) were estimated from the 20% of above ground stem biomass. Carbon stock and CO_2 sequestration were estimated from the dry weight of AGB and BGB. A total of 20 species in 16 different quadrats in three ecological zones and overall SMF was recorded. Among 20 species 10 dominant tree species were considered on the basis of abundance (number) for the estimation of AGB, BGB and CO_2 sequestration. Species wise mean AGB (ton/ha) of 10 dominant mangrove trees are in order *Heritiera fomes* (186.423) > *Excoecaria agallocha* (28.752) > *Avicennia officinalis* (24.082) > *Ceriops decandra* (5.021) > *Cynometra ramiflora* (1.403) > *Tamarix dioica* (0.592) > *Xylocarpus moluccensis* (0.500) > *Bruguiera gymnorrhiza* (0.307) > *Aegiceras corniculata* (0.241) > *Aglaia cuculata* (0.038).Species wise mean BGB (ton/ha) of 10 dominant mangrove trees are in order *H. fomes* (34.99) > *E. agallocha* (4.94) > *A. officinalis* (4.79) > *C. decandra* (0.704) > *X. moluccensis* (0.47) > *C. ramiflora* (0.15) > *B. gymnorrhiza* (0.018) > *A. corniculata* (0.015) > *T. dioica* (0.008) >*A. cuculata* (0.004). The total CO_2 sequestered (above ground and below ground) in overall SMF (considered land area 4143 km^2) was 192.869 megaton.

Introduction

Mangrove communities mainly occur along subtropical and tropical coastlines; about 75% of sub-tropical and tropical countries have mangrove forest (William 2005). Mangroves contribute in the protection of coastline (Vermatt and Thampanya 2006), climate regulation, helping in counter balancing anthropogenic CO_2 emissions through capturing and preserving significant amounts of carbon (Mcleod *et al*. 2011, Siikamäki *et al*. 2012). In global terms, approximately 80% of the above ground biomass and 40% of carbon of below ground are stored in the forests (Kirschbaum *et al.* 1996). In the global carbon cycle, tropical forests act as an important component which represents 30–40% of the terrestrial net primary production (Clark *et al*. 2001). The mangroves have about nearly half of the total global net primary production (NPP) of all coastal wetlands and is estimated to be 218 $Tgha^{-1}$ of carbon (Bouillon *et al*. 2008). Thus, mangroves are considered one of the most carbon-rich forest types in the tropics (Donato *et al.* 2011), along with providing numerous important ecosystem services. At the equatorial latitudes the biomass of mangrove forests is found to be highest. Their global mean biomass (247 t/ha) is almost equal to the global average biomass of evergreen forests of tropical humid (Donato *et al.* 2012). Mangroves warrant preservation and restoration because they are increasingly considered as carbon-rich ecosystems (Van Lavieren *et al*. 2012).

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Global emissions of carbon have increased since the inception of the industrial revolution. Concentration of carbon dioxide (CO_2) in the atmosphere has increased and reached 360 ppm by the end of the year 2000 and the increase is about 25% from pre-industrial levels and the level reached about 389 ppm (Chapin *et al.* 2011). In carbon sequestration from the atmosphere, mangrove forests play an important role and they can sequester four times carbon per unit area compared to the terrestrial forests of the tropics (Khan *et al.* 2007). In climate change mitigation and reducing emissions from deforestation and degradation (REDD+) schemes mangroves have been considered as an important component (Siikamäki *et al.* 2012). ‘‘Blue carbon’’ has been defined in the United Nations Environment Programme (UNEP) report “as to carbon captured by living organisms and stored in sediments of coastal wetlands including mangroves, salt marshes and sea grasses” (Nellemann *et al.* 2009).

Majority of works on Bangladesh Sundarbans focused on the species and phytoplankton diversity, water quality, edaphic features forest cover changes (Ahmed *et al*. 2011, 2018, Ataullah *et al*. 2018), very few have discussed about the C-stock and sequestration. Some works have been done on the Indian parts of Sundarbans (Joshi and Ghose 2014, Bhattacharyya *et al*. 2015, Sahu *et al*. 2016), but there is no substantial data on the amount of CO_2 sequestered by different species of mangroves of Bangladesh Sundarbans and the reserve of carbon in the soil of SMF except few works (Khan *et al.* 2007, Hossain *et al.* 2012). Thus the present study aims to determine biomass of above ground vegetative parts (stem, branch, leaf), below ground biomass, C- stock and sequestration by dominant mangrove species of Bangladesh Sundarbans.

Materials and Methods

The study was carried out in the different locations of Sundarban Mangrove Forests (SMF) of Bangladesh (Fig. 1). Sampling was performed from 28 March to 1 April 2016 in 16 locations of the SMF in three ecological zones (oligohaline, mesohaline and polyhaline zone). Plots of 10 m ×10 m size were established in these locations for the plant parts i.e. stem, branch and leaf collection (Bhattacharyya *et al.* 2015) (Table 1). The dominant mangrove species were selected by the highest abundance (in terms of number) of each species. The above ground stem, branch and leaf biomass of individual trees of 3 dominant species in each plot was estimated (Bhattacharyya *et al.* 2015). The average values of 3 ecological zones were also calculated along with average values of 16 plots that were finally converted into biomass of dominant mangrove species (in tons) per hectare in SMF. From these values amount of C present and hence CO_2 sequestered by each dominant species were calculated in quadrats and zones wise, and of total SMF.

The above ground biomass (AGB) of stem was estimated for each species in every quadrat by using non-destructive method in which the diameter at the breast height (DBH) was measured with a measuring tape and height with bamboo stick. Form factor was estimated to find out the tree volume (V) using the standard formula given by Bitterlich (1984).

$$F = \frac{2h_1}{3h}$$

where, F = Form factor, h_1 = Height at which diameter is half dbh, h = Total height of target tree.

The Volume (V) was estimated by using the following formula (Bhattacharyya *et al.* 2015): $V = FH\pi R^2$

where, V = Volume of tree, F = Form factor, H = Total height of target tree, R = Radius of tree derived from its DBH.

Specific gravity was estimated (Koul and Panwar 2008) taking the stem cores, which was further used to calculate biomass of the stem using the maximum moisture method such as:

$$G = \frac{1}{\dfrac{M_n - M_o}{M_o} + \dfrac{1}{G_{so}}}$$

where, G = The specific gravity based on gross volume, Mn = The weight of saturated volume of sample, M_o = The weight of oven-dried sample, G_{so} = The average density of wood substances equal to 1.53.

Thus, the weight of wood was estimated using the following equation (Koul and Panwar 2008): Biomass (B) = Specific gravity (G) × Volume (V)

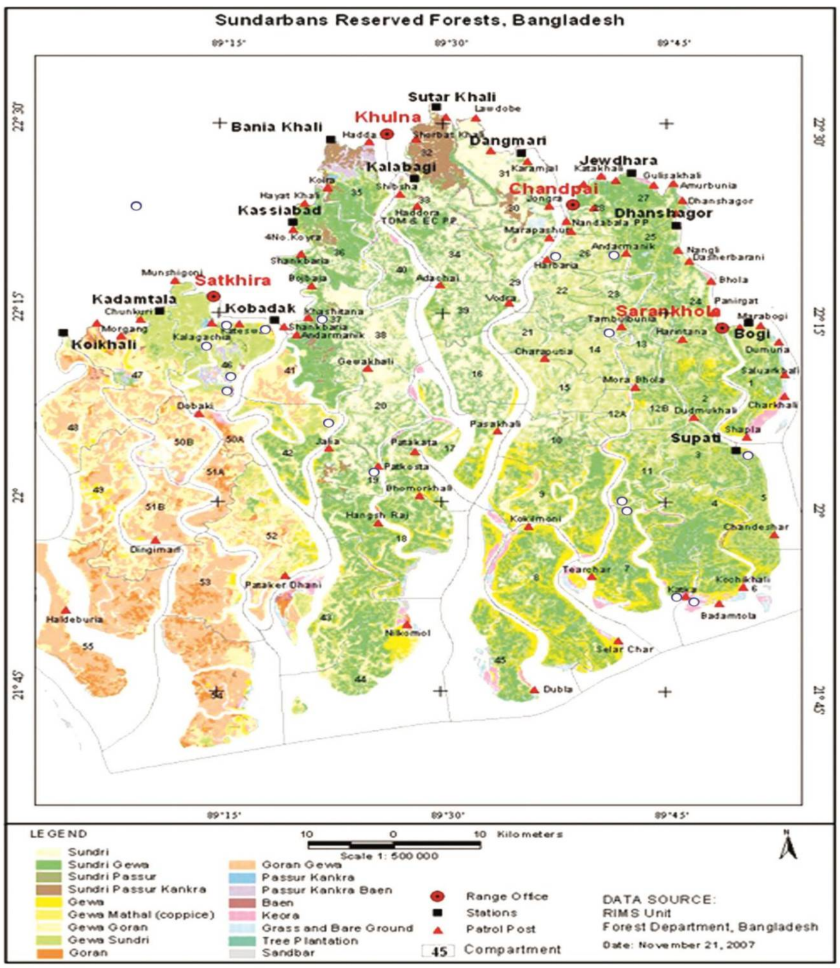

Fig. 1. The map of the SMF from where different quadrats were taken with distribution of mangrove plant species (BFD 2013) (0 = circles indicate the study areas).

The total number of branches irrespective of size was counted on each of the sample trees. On the basis of basal diameter generally 6-10 cm size (medium class) of stem samples were collected. Fresh weight of three branches was recorded separately. Dry weight of branches was estimated using the following equation (Chidumaya 1990):

$$B_{dwi} = B_{fei}/1+M_{odbi}$$

where, B_{dwi}= Oven dry weight of branches, B_{fei} = Fresh/green weight of branches M_{odbi}=Moisture content of branches on dry weight basis.

Total branch biomass (dry weight) per sample tree was determined as per the expression:

$$B_{db} = n_1bw_1 + n_2bw_2 + n_3bw_3 = S\ n_ibw_i$$

where, B_{db} = Dry branch biomass per tree, ni = Number of branches in the *i*-th branch group

This procedure was followed for all the dominant mangrove species separately.

Leaves from three branches of individual tree were removed. One tree of each species per plot was considered for estimation. The leaves were weighed and oven-dried separately (Chidumaya 1990) to a constant weight at 80 ± 5°C. The average leaf biomass was then calculated by multiplying the average biomass of the leaf per branch with the number of branches in a single tree and the average number of trees in a plot. The leaf biomass was estimated by the following equation (Bhattacharyya *et al.* 2015):

$$L_{db} = n_1L_{w1}N_1 + n_2L_{w2}N_2 +n_3L_{w3}N_3$$

where, L_{db} = Dry leaf biomass of dominant mangrove species per plot, n_1 to n_3 = Number of branches of each tree of dominant species, L_{w1} to L_{w3} = dry weight of leaf removed from three branches of each of the dominant species, N_1 to N_3 = Number of trees per species in the plot.

The root system weighs about 20% as much as the above ground weight of the tree (DeWald *et al*. 2005, Hanif *et al. 2*014). So, the below ground biomass was estimated from the 20% of the above ground stem biomass of the tree.

The rate of carbon sequestration depends on the growth characteristics of the tree species, the conditions for growth where the tree is planted or growing and the density of the tree's wood. For estimation of carbon sequestration dry weight (dry biomass) of plant vegetative part i.e. stem, branch and leaf were taken. The average carbon content is generally 50% of the plant parts of the total volume (Brown *et al.*1989, Birdsey 1992). Therefore, to determine the weight of carbon is to multiply the dry weight of the plant vegetative part by 50%. To determine the weight of carbon dioxide sequestered in the plant vegetative parts, the following formula was used:

CO_2 is composed of 1 molecule of Carbon and 2 molecules of Oxygen, so

The atomic weight of Carbon = 12.001115; The atomic weight of Oxygen = 15.9994. The weight of CO_2 = C+2×O = 43.999915; The ratio of CO_2 to C = 43.999915 ÷ 12.001115 = 3.6663.

Therefore, to determine the weight of carbon dioxide sequestered in the tree, the weight of carbon in the plant vegetative parts were multiplied by 3.6663.

Below ground carbon sequestration was estimated from below ground biomass (BGB) of the trees species. The dry weight of BGB of each species was determined from AGB. From dry weight, CO_2 sequestration was estimated by the above formula.

From the above equation one could estimate the total amount of carbon sequestration in each plant species per 10 m × 10 m size plot or quadrats. This carbon content was finally converted to tons per hectare of three ecological zones and of overall SMF.

Results and Discussion

The biomass and productivity of mangrove forests have been studied for wood production, forest conservation, ecosystem management and amount of C- sequestration (Putz and Chan 1986, Tamai *et al.* 1986, Komiyama *et al.* 1987, Clough and Scott 1989, McKee 1995, Ong *et al.* 1995). Forest biomass is an essential factor in environmental and climate modeling. Forest biomass can be sub-divided into its components such as stem, branch, and foliage (Qisheng *et al.* 2013). The present study described on the biomass production and hence C-sequestration by 10 dominant plant species of SMF.

Results of 10 dominant mangrove species studied for stem biomass determination from three ecological zones of overall SMF are presented in Table 1. The mean above ground stem biomass of these species were *H. fomes* (174.96 t/ha), *E. agallocha* (24.724 t/ha), *A. officinalis* (23.978 t/ha), *C. decandra* (3.520 t/ha), *C. ramiflora* (0.772 t/ha), *X. moluccensis* (0.366 t/ha), *B. gymnorrhiza* (0.092 t/ha), *A. corniculata* (0.075 t/ha), *T. dioica* (0.043 t/ha) and *A. cuculata* (0.021 t/ha) (Table 2). Bhattacharyya *et al.* (2015) found that the above ground stem biomass of the dominant mangrove trees of Indian Mangroves of Sagar Island of Indian Sundarbans were *E. agallocha* 5.83 t/ha and *A. officinalis* 6.70 t/ha. These values are comparatively much lower than those of the present results. Komiyama *et al.* (1987) reported that the secondary mangrove (*Ceriops tagal*) forest at Southern Thailand, the above ground stem biomass of the dominant mangrove trees were *E. agallocha* 56.81% and *A. officinalis* 59.50%.

Table 1. Distribution of major plant species in three ecological zones of SMF from where plant parts were collected.

Name of species	Oligohaline zone						Mesohaline zone					Polyhaline zone				
	Q1	Q2	Q3	Q4	Q5	Q16	Q6	Q7	Q8	Q9	Q11	Q15	Q10	Q12	Q13	Q14
Aegiceras corniculata Blanco.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Aglaia cuculata (Roxb.) Pellegr.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Avicennia officinalis L.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bruguiera gymnorrhiza (L.) Lamk.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Ceriops decandra (Griff.) Ding Hou	-	-	+	+	+	-	-	-	-	+	+	-	+	+	-	+
Cynometra ramiflora L.	-	-	-	-	+	-	-	-	+	+	-	-	-	-	-	-
Excoecaria agallocha L.	+	-	+	+	-	+	+	+	-	-	+	+	+	-	+	-
Heritiera fomes Buch.-Ham.	+	+	+	+	+	+	-	-	+	+	-	-	+	-	+	-
Tamarix dioica Roxb. *ex* Roth	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Xylocarpus moluccensis (Lamk.) M. Roem.	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-

+ = Present, - = Absent.

From Table 3 it is apparent that the mean above ground branch biomass of 10 dominant mangrove species were *H. fomes* (7.840 t/ha), *E. agallocha* (2.799 t/ha), *C. decandra* (1.683 t/ha), *C. ramiflora* (0.489 t/ha), *T. dioica* (0.342 t/ha), *A. officinalis* (0.154 t/ha), *B. gymnorrhiza* (0.133 t/ha), *A. corniculata* (0.099 t/ha), *X. moluccensis* (0.092 t/ha) and *A. cuculata* (0.012 t/ha). Bhattacharyya *et al.* (2015) found that the above ground branch biomass of the dominant mangrove trees of Indian Sundarbans were 2.56 t/ha in *E. agallocha* and 3.15 t/ha in *A. officinalis.* Komiyama *et al.* (1987) reported that the above ground branch biomass of the dominant mangrove trees was 26.31% in *E. agallocha* and 27.98% in *A. officinalis.*

Table 2. Mean above ground stem biomass of dominant mangrove species of three ecological zone and overall Sundarban mangrove forests.

Name of species	Oligohaline Zone		Mesohaline Zone		Polyhaline Zone		Over all	
	kg/Q	t/ha	kg/Q	Ton /ha	kg/Q	t/ha	kg/Q	t/ha
A. corniculata	-	-	-	-	3.005	0.300525	0.751	0.075
A. cuculata	0.551	0.055	-	-	-	-	0.206	0.021
A. officinalis	639.417	63.942	-	-	-	-	239.781	23.978
B. gymnorrhiza	0.848	0.085	-	-	2.419	0.242	0.923	0.092
C. decandra	7.666	0.766	83.707	8.371	3.712	0.371	35.193	3.520
C. ramiflora	1.414	0.141	19.164	1.916	-	-	7.717	0.772
E. agallocha	175.086	17.508	426.260	42.626	86.960	8.696	247.245	24.724
H. fomes	4080.494	408.049	544.414	54.441	61.055	6.105	1749.604	174.960
T. dioica	-	-	1.141	0.114	-	-	0.428	0.043
X. moluccensis	-	-	2.037	0.204	91.934	9.193	3.665	0.366

Q= Quadrat, ha= hectare, - = Plants not found in the quadrat/zone.

Table 3. Mean above ground branch biomass of dominant mangrove species of three ecological zone and overall Sundarban mangrove forests.

Name of species	Oligohaline Zone		Mesohaline Zone		Polyhaline Zone		Over all	
	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha
A. corniculata	-	-	-	-	3.999	0.399	0.999	0.099
A. cuculata	0.321	0.032	-	-	-	-	0.120	0.012
A. officinalis	4.102	0.410	-	-	-	-	1.538	0.154
B. gymnorrhiza	*	*	-	-	5.317	0.532	1.329	0.133
C. decandra	11.755	1.175	12.421	1.242	31.056	3.106	16.830	1.683
C. ramiflora	1.577	0.156	11.464	1.146	-	-	4.890	0.489
E. agallocha	15.241	1.524	46.337	4.633	19.631	1.963	27.999	2.799
H. fomes	182.104	18.210	17.079	1.708	14.821	1.482	78.399	7.840
T. dioica	-	-	9.120	0.912	-	-	3.419	0.342
X. moluccensis	0.415	0.041	-	-	3.059	0.306	0.920	0.092

* = Branch was not collected, Q = Quadrat, ha = hectare, - = Plants not found in the quadrat/zone.

The mean leaf biomass of 10 dominant mangrove trees of overall SMF were *H. fomes* (3.623 t/ha), *E. agallocha* (1.229 t/ha), *C. decandra* (0.818 t/ha), *T. dioica* (0.207 t/ha), *C. ramiflora* (0.142 t/ha), *A. officinalis* (0.089 t/ha), *B. gymnorrhiza* (0.082 t/ha), *A. corniculata* (0.067 t/ha), *X. moluccensis* (0.042 t/ha) and *A. cuculata* (0.005 t/ha) (Table 4). Bhattacharyya *et al.* (2015) have found that the above ground leaf biomass of the dominant mangrove trees of Indian Sundarbans were as follows: *E. agallocha* (1.34 t/ha) and *A. officinalis* (1.41 t/ha). The amount of leaf biomass of *E. agallocha* was almost similar but the values are comparatively greater in *A. officinalis* (0.089 t/ha). The values of the present study are comparatively lesser to the records of other workers like 12.1 -15.0 t/ha in *Avicennia* forests (Briggs 1977), 6.2 - 20.2 t/ha in *Rhizophora apiculata* young plantations (Aksomkoae 1975), 13.3 t/ha in *Rhizophora* patch (De la Cruz and Banaag 1967). The plant growth, survival and biomass of mangroves depend on appropriate dilution of the brackish water system with fresh water (Bhattacharyya *et al.* 2015). In the polyhaline zone of SMF of Bangladesh hardly testify that such dilution as the freshwater discharge reaches the area in lesser amount specially during the lean period.

Table 4. Mean leaf biomass of dominant mangrove species of three ecological zone and overall Sundarban mangrove forests.

Name of species	Oligohaline Zone		Mesohaline Zone		Polyhaline Zone		Over all	
	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha
A. corniculata	-	-	-	-	2.676	0.268	0.669	0.067
A. cuculata	0.130	0.013	-	-	-	-	0.049	0.005
A. officinalis	2.387	0.239	-	-	-	-	0.895	0.089
B. gymnorrhiza	*	*	-	-	3.287	0.329	0.822	0.082
C. decandra	6.363	0.636	6.821	0.682	12.952	1.295	8.182	0.818
C. ramiflora	0.292	0.029	3.496	0.350	-	-	1.421	0.142
E. agallocha	4.802	0.480	20.957	2.096	10.522	1.052	12.290	1.229
H. fomes	85.285	4.528	7.147	0.715	6.267	0.627	36.229	3.623
T. dioica	-	-	5.520	0.552	-	-	2.070	0.207
X. moluccensis	0.184	0.018	-	-	1.409	0.141	0.421	0.042

* = Leaf was not collected, Q = Quadrat, ha = hectare, - = Plants not found in the quadrat/zone.

Total above ground biomass (AGB) was calculated by summation of stem, branch and leaf biomasses. It showed that maximum AGB was found in *H. fomes* (13.697 t/ha) and minimum in *A. cuculata* (0.021 t/ha) (Table 5). Mangroves are major source and storehouse of carbon. The global storage of carbon in mangrove biomass is estimated to be 4.03 pg, and 70% of this C occurs in coastal margins from 0^0 to 10^0 latitude (Twilley *et al.* 1992). The mean CO_2 sequestered by above ground vegetative parts (stem) of 10 dominant mangrove species in overall SMF were *H. fomes* (279.031 t/ha), *E. agallocha* (39.418 t/ha), *A. officinalis* (38.24 t/ha), *C. decandra* (5.616 t/ha), *X. moluccensis* (3.787 t/ha), *C. ramiflora* (1.229 t/ha), *B. gymnorrhiza* (0.147 t/ha), *A. corniculata* (0.119 t/ha), *T. dioica* (0.067 t/ha) and *A. cuculata* (0.033 t/ha) (Table 6). From Table 7 it is apparent that the mean CO_2 sequestered by above ground vegetative parts (branch) of 10 dominant

Table 5. Above ground biomass (t/ha) of ten dominant mangrove species in the Bangladesh Sundarbans.

Vegetative parts Name of spp.	Stem	Branch	leaf	Total
A. corniculata	0.002	0.099	0.067	0.168
A. cuculata	0.004	0.012	0.005	0.021
A. officinalis	1.199	0.154	0.089	1.442
B. gymnorrhiza	0.014	0.133	0.082	0.229
C. decandra	0.134	0.683	0.818	1.635
C. ramiflora	0.073	0.489	0.142	0.704
E. agallocha	0.705	2.799	1.229	4.733
H. fomes	2.234	7.840	3.623	13.697
T. dioica	0.0009	0.342	0.207	0.550
X. moluccensis	0.366	0.092	0.042	0.500

Table 6. Mean Carbon dioxide (CO_2) sequestered by above ground vegetative parts (stem) of 10 dominant mangrove species of three ecological zones and overall SMF.

Name of species	Oligohaline Zone		Mesohaline Zone		Polyhaline Zone		Over all	
	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha
A. corniculata	-	-	-	-	4.784	0.478	1.196	0.119
A. cuculata	0.877	0.088	-	-	-	-	0.329	0.033
A. officinalis	101.974	10.197	-	-	-	-	382.403	38.240
B. gymnorrhiza	1.356	0.135			3.863	0.386	1.474	0.147
C. decandra	1.227	0.123	133.531	13.353	5.941	0.594	56.159	5.616
C. ramiflora	2.259	0.226	30.509	3.051	-	-	12.288	1.229
E. agallocha	279.241	27.924	679.500	67.950	138.604	13.860	394.178	39.418
H. fomes	6507.643	650.764	868.287	86.829	97.365	9.736	2790.315	279.031
T. dioica	-	-	1.786	0.179	-	-	0.670	0.067
X. moluccensis	-	-	3.248	0.325	146.610	14.661	37.870	3.787

Q = quadrat, ha = hectare, - = plants not found in the quadrat/zone.

mangrove species in overall SMF were *H. fomes* (14.372 t/ha), *E. agallocha* (5.133 t/ha), *C. decandra* (3.085 t/ha), *C. ramiflora* (0.896 t/ha), *T. dioica* (0.627 t/ha), *A. officinalis* (0.282 t/ha), *B. gymnorrhiza* (0.244 t/ha), *A. corniculata* (0.183 t/ha), *X. moluccensis* (0.169 t/ha) and *A. cuculata* (0.022 t/ha).

Table 7. Mean Carbon dioxide (CO_2) sequestered by above ground vegetative parts (branch) of 10 dominant mangrove species of three ecological zones and overall SMF.

Name of species	Oligohaline Zone		Mesohaline Zone		Polyhaline Zone		Over all	
	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha
A. corniculata	-	-	-	-	7.331	0.7331	1.833	0.183
A. cuculata	0.588	0.0588	-	-	-	-	0.220	0.022
A. officinalis	7.520	0.7520	-	-	-	-	2.820	0.282
B. gymnorrhiza	*	*	-	-	6.497	0.6497	2.436	0.244
C. decandra	21.549	2.1549	136.613	13.6613	56.930	5.6930	30.852	3.085
C. ramiflora	2.891	0.2891	21.016	2.1016	-	-	8.965	0.896
E. agallocha	27.939	2.7939	84.943	8.4943	35.986	3.5986	51.327	5.133
H. fomes	333.824	33.3824	31.308	3.1308	27.168	2.7168	143.717	14.372
T. dioica	-	-	16.718	1.6718	-	-	6.269	0.627
X. moluccensis	0.760	0.0760	-	-	5.607	0.5607	1.687	0.169

* = Branch was not collected. Q = quadrat, ha = hectare, - = plants not found in the quadrat/zone.

The mean CO_2 sequestered by above ground vegetative parts (leaf) of 10 dominant mangrove species in overall SMF were *H. fomes* (6.641 t/ha), *E. agallocha* (2.252 t/ha), *C. decandra* (1.499 t/ha), *T. dioica* (0.379 t/ha), *C. ramiflora* (0.260 t/ha), *A. officinalis* (0.164 t/ha), *B. gymnorrhiza* (0.151 t/ha), *A. corniculata* (0.123 t/ha), *X. moluccensis* (0.077 t/ha) and *A. cuculata* (0.009 t/ha) (Table 8). The results showed that total carbon dioxide sequestration in the above ground biomass of ten dominant mangrove species in overall SMF were *H. fomes* (300.044 t/ha), *E. agallocha*

(46.803 t/ha), *A. officinalis* (38.686 t/ha), *C. decandra* (10.2 t/ha), *X. moluccensis* (4.033 t/ha), *C. ramiflora* (2.385 t/ha), *T. dioica* (1.073 t/ha), *B. gymnorrhiza* (0.542 t/ha), *A. corniculata* (0.425 t/ha) and *A. cuculata* (0.064 t/ha) (Table 9). Here the maximum CO_2sequestrated in overall SMF was done by *H. fomes* (300.044 t/ha). On the other hand, minimum CO_2 sequestrated in overall SMF was done by *A. cuculata* (0.064 t/ha) (Table 9). For accelerating the biomass of mangrove species in SMF, these figures can be manifested through effective soil management and proper dilution of the system with freshwater. Although in this study the role of mangroves as sink of carbon is established but more endeavor towards standardization of the techniques is needed to

Table 8. Mean Carbon dioxide (CO_2) sequestered by above ground vegetative parts (leaves) of 10 dominant mangrove species of three ecological zones and overall SM.

Name of species	Oligohaline Zone		Mesohaline Zone		Polyhaline Zone		Over all	
	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t /ha	kg/Q	t/ha
A. corniculata	-	-	-	-	4.905	0.4905	1.226	0.123
A. cuculata	0.238	0.024	-	-	-	-	0.089	0.009
A. officinalis	4.376	0.437	-	-	-	-	1.641	0.164
B. gymnorrhiza	*	*	-	-	6.026	0.6026	1.506	0.151
C. decandra	11.663	1.1663	12.503	1.2503	23.742	2.374	14.998	1.499
C. ramiflora	0.536	0.0536	6.408	0.641			2.604	0.260
E. agallocha	8.802	0.880	38.417	3.841	19.288	1.929	22.529	2.252
H. fomes	156.340	15.634	13.101	1.310	11.488	1.149	66.412	6.641
T. dioica	-	-	10.119	1.0119			3.794	0.379
X. moluccensis	0.337	0.0337	-	-	2.582	0.258	0.772	0.077

* = Leaf was not collected. Q = quadrat, ha = hectare, - = plants not found in the quadrat/zone.

Table 9. Above ground Carbon stock (t/ha) of ten dominant mangrove species in the Bangladesh Sundarbans.

Vegetative parts Name of species	Stem	Branch	leaf	Total
A. corniculata	0.119	0.183	0.123	0.425
A. cuculata	0.033	0.022	0.009	0.064
A. officinalis	38.240	0.282	0.164	38.686
B. gymnorrhiza	0.147	0.244	0.151	0.542
C. decandra	5.616	3.085	1.499	10.200
C. ramiflora	1.229	0.896	0.260	2.385
E. agallocha	39.418	5.133	2.252	46.803
H. fomes	279.031	14.372	6.641	300.044
T. dioica	0.067	0.627	0.379	1.073
X. moluccensis	3.787	0.169	0.077	4.033

reach exactness. Accurate measurement and accounting for changes in carbon stores are not only important for certification and verification of carbon credits, but also for helping stabilize market prices for such credit system. Incorrect accounting or forecasting of forest carbon stores could interrupt the market for credits, as evidenced by the recent market crash in Europe that resulted from a lack of transparency, poor forecasting of emissions and over allocations of allowances (Scarborough and Meiners 2007).

A total of 10 dominated mangrove species were studied for below ground biomass (BGB) estimation and CO_2 sequestration from SMF from those plants above ground biomass and CO_2 sequestration were measured. The mean BGB of 10 dominant mangrove species in overall SMF were *H. fomes* (34.99 t/ha), *E. agallocha* (4.94 t/ha), *A. officinalis* (4.79 t/ha), *C. decandra* (0.704 t/ha), *X. moluccensis* (0.47 t/ha), *C. ramiflora* (0.15 t/ha), *B. gymnorrhiza* (0.018 t/ha), *A. corniculata* (0.015 t/ha), *T. dioica* (0.008 t/ha) and *A. cuculata* (0.004 t/ha) (Table 10).

Table 10. Mean below ground biomass of 10 dominant mangrove species of three ecological zones and overall SMF.

Name of species	Oligohaline zone		Mesohaline zone		Polyhaline zone		Overall	
	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha
A. corniculata	-	-	-	-	0.6	0.06	0.15	0.015
A. cuculata	0.11	0.01	-	-	-	-	0.04	0.004
A. officinalis	127.88	12.79	-	-	-	-	47.95	4.79
B. gymnorrhiza	0.17	0.017	-	-	0.48	0.048	0.18	0.018
C. decandra	1.54	0.15	16.74	1.67	0.74	0.074	7.04	0.704
C. ramiflora	0.28	0.028	3.83	0.38	-	-	1.54	0.15
E. agallocha	35.02	3.50	85.21	8.52	17.38	1.74	49.43	4.94
H. fomes	816.09	81.61	108.89	10.89	12.21	1.22	349.92	34.99
T. dioica	-	-	0.22	0.02	-	-	0.084	0.008
X. moluccensis	-	-	0.41	0.04	18.38	1.84	4.75	0.47

- = Plant was absent, Q = quadrat, ha = hectare.

The mean CO_2 sequestered by below ground biomass (BGB) of 10 dominant mangrove species in overall SMF were: *H. fomes* (46.50 t/ha), *E. agallocha* (6.57 t/ha), *A. officinalis* (6.37 t/ha), *C. decandra* (0.94 t/ha), *X. moluccensis* (0.63 t/ha),*C. ramiflora* (0.205 t/ha), *B. gymnorrhiza* (0.024 t/ha), *A. corniculata* (0.02 t/ha), *T. dioica* (0.011 t/ha) and *A. cuculata* (0.005 t/ha) (Table 11).

Mangrove forest ecosystem is also one of the important carbon sinks in the tropics. The Bangladeshi part of SMF sequestered CO_2 equivalent to 4.8 Megatons (Mt), which is equivalent to 10% of Bangladesh's annual CO_2 credited with an annual emission (MEF-FD 2011). However, due to its enormous socio-ecological value, the Sundarbans is threatened by both natural (i.e., coastal erosion, tropical cyclones, and sea level rise) and anthropogenic (i.e. over harvesting, agriculture, shrimp farming, and pollution) factors (Ghosh *et al.* 2015). While there has been extensive research on mangroves both in tropical and sub-tropical regions of the world, there is limited available information on the community structure and biomass of mangrove trees, carbon stock in soil in the Sundarbans (Joshi and Ghose 2014) especially in Bangladesh Sundarbans. The present study will provide information on the aboveground and below ground biomass and carbon stock in SMF.

Aboveground biomass was depending on the structural characteristics of the trees and tidal inundation significantly affected the biomass of the trees (Joshi and Ghose 2014). Mangroves, in general, prefer brackish water environment and in extreme saline condition stunted growth was

Table 11. Mean CO_2 sequestered by below ground parts (root) of 10 dominant mangrove species of three ecological zones and overall SMF.

Name of species	Oligohaline zone		Mesohaline zone		Polyhaline zone		Overall	
	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha	kg/Q	t/ha
A. corniculatum	-	-	-	-	0.80	0.08	0.20	0.02
A. cuculata	0.15	0.015	-	-	-	-	0.055	0.005
A. officinalis	169.96	16.99	-	-	-	-	63.73	6.37
B. gymnorrhiza	0.22	0.022	-	-	0.64	0.064	0.24	0.024
C. decandra	2.04	0.204	22.25	2.22	0.99	0.099	9.36	0.94
C. ramiflora	0.38	0.038	5.08	0.51	-	-	2.05	0.205
E. agallocha	46.54	4.65	113.25	11.32	23.10	2.31	65.70	6.57
H. fomes	1084.61	108.46	144.71	14.47	16.23	1.62	465.05	46.50
T. dioica	-	-	0.30	0.03	-	-	0.11	0.011
X. moluccensis	-	-	0.54	0.054	24.43	2.44	6.31	0.63

- = Plant was absent, Q = quadrat, ha = hectare.

observed (Mitra *et al.* 2004). Species wise above ground biomass (t/ha) in 10 dominant mangrove trees are in the following chronological order *H. fomes* > *E. agallocha* > *A. officinalis* > *C. decandra* > *C. ramiflora* > *T. dioica*> *X. moluccensis* >*B. gymnorrhiza* > *A. corniculata* > *A. cuculata.* In the present study, the results of carbon stock in the maximum above ground biomass and hence CO_2 sequestered by the 10 dominated tree are in order: *H. fomes* > *E. agallocha* > *A. officinalis* > *C. decandra* > *X. moluccensis* > *C. ramiflora* > *T. dioica* > *B. gymnorrhiza* >*A. corniculata* > *A. cuculata.*

For total CO_2 sequestration estimation, these ten dominant mangroves were considered for overall SMF. The total CO_2 sequestered (above ground and below ground) in overall SMF (considered land area was 4143 km^2) was 192.869 megaton.

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