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Spatial Variation of Fine Roots Carbon Stock in Sundarbans, Bangladesh

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BANGLADESH
August 2018

Spatial Variation of Fine Roots Carbon Stock in Sundarbans, Bangladesh

B.Sc. Thesis

By

Shamim Ahmed

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This thesis work has been prepared and submitted to Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh for the fulfillment of the 4-years professional BSc. (Hons.) degree in forestry.

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DECLARATION

I, hereby, declare that the results submitted in this thesis are entirely the authors own investigations and this work has not previously been accepted in substance for any degree and is not being concurrently submitted in a candidate for any degree to any other university or institution.

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APPROVAL

The style and format of the presented project thesis which entitled **"Spatial Variation of Fine Roots Carbon Stock in Sundarbans, Bangladesh"** has been carried out by Shamim Ahmed (student ID: 140535) under my direct supervision and submitted to Forestry and Wood Technology Discipline Khulna University, Khulna, Bangladesh.

I recommended that the content of the project report can be accepted in the partial fulfillment of the requirements for the 4 years' professional BSc. (Hons.) degree in Forestry has been approved.

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DEDICATION

This work is dedicated……….

To my cherished, adored and respected

PARENTS

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ABSTRACT

Limited information on fine roots is hindering understanding of geographical scale variations in belowground carbon stock across the three different saline zones in Sundarbans, Bangladesh. Fine roots biomass (≤ 2mm in diameter) was studied in three different saline zones in Sundarbans, in associated with, stand structure and carbon storage both in above and below ground within the classified saline zones, in where no previous studied was found on fine root biomass and amalgamation with carbon storage. Initially, sample plots were taken from each salinity zone which covered 2100 m^2, 1900 m^2 and 1700 m^2, in addition to 20, 28 and 32 soil samples for fine roots biomass estimation in oligohaline, mesohaline and polyhaline zone respectively. Moreover, a soil sample was alienated into 10 cm, 20 cm and 30 cm by following depth of the soil, furthermore, fine root split into 2 mm, 1 mm and 0.5 mm and measured fine root biomass mean 33.84 ± 4.0 Mg ha^{-1} overall. Among the three-saline zones, oligohaline contributed the highest amount of fine root biomass roughly 46.7 ± 6.6 Mg ha^{-1}, in addition to, 28.2 ± 2.81 Mg ha^{-1} in mesohaline and 26.7 ± 2.8 Mg ha^{-1} in polyhaline zone. Fine root biomass was influenced by salinity zone rather than soil depth. Among the three diameters class 2 mm fine root contributed a key amount of biomass in both different depth and salinity zones. On the other hand, mean above-ground, below-ground, and Total Biomass Carbon (TBC) of the three saline zone areas were 116.0 ± 32.9, 71.1 ± 15.5 and 187.1 ± 48.4 Mg ha^{-1} correspondingly. *Heritiera fomes* dominantly contributed a higher amount of biomass in the different saline zone which represents higher IvI value. In contrast, Sonneratia apetala donated the highest amount of biomass in polyhaline zone, notably, *Excoecaria agallocha* has maintained a great amount of biomass additionally in all zones, although, Avicennia *officinalis* added the handsome color of amount biomass in the oligohaline zone. Mangrove communities growing in different saline zones of the Sundarbans, Bangladesh show high species richness and carbon stock both above and below, denoting their ecological significance, this need to be considered in the future decision-making process for the area as well as in understanding the role of Sundarbans on mitigating the effects of climate change.

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1.0 Introduction

1.1 Background of the study

Around the globe, forests contain 80% of all above-ground carbon (C) and 40% of all below-ground terrestrial Carbon(C) (Dixon et al. 1994; Finér et al. 2011) and this forest are playing a critical and crucial role to alleviate climate change by accumulating atmospheric carbon (Adame et al. 2013). Mangrove forests are reflected among the world's most fecund ecosystems, as well as unique wetland ecosystems in intertidal coastal regions of the tropics and subtropics (Lugo & Snedaker 1975; Nagarajan *et al.* 2008; Kamruzzaman et al. 2018) Comparing with terrestrial forests, mangroves are efficiently sunk and sequestering four times higher carbon per unit area in the tropics (Khan et al. 2007; Donato et al. 2011; Rahman et al. 2015).

Mangroves forests provide numerous ecosystem services, including nutrient cycling, sediment trapping, protection from cyclones and tsunamis, habitat for numerous organisms and wood for lumber and fuel (Lugo and Snedeker, 1974; Dinerstein et al., 1995; Kasawani et. al., 2007; Kauffman and Donato 2012; Paul 2013) Among the most important of these functions but poorly quantified—is ecosystem carbon (C) storage (Paul 2013). The estimated carbon stored in these ecosystems is so large that it makes mangrove important for climate change mitigation, however, these ecosystems are especially vulnerable to climate and land use change.

Biomass and carbon storage of mangrove forest have been studied previously in different mangrove forests across the world (Putz & Chan 1986; Day *et al.* 1996; Saintilan 1997, Komiyama *et al.* 2000) and the purpose of biomass estimation and carbon storage of mangrove forests are mainly in terms of ecosystem management (Kauffman *et al.* 2011; Wang *et al.* 2013; Saito *et al.* 2014; Liu *et al.* 2014; Kamruzzaman et al. 2018), information on fine root biomass and carbon storage can be elevated this management of ecosystem. Mangrove forests are also highly productive ecosystems with a large net primary productivity (NPP), being reflected by huge biomasses (Putz and Chan 1986; Amarasinghe and Balasubramaniam 1992; Komiyama et al. 2008; Kamruzzaman et al. 2017). However, some studies have shown that a large amount of the mangrove biomass is in the below ground level root system (Komiyama et al. 1987; Ong et al. 2004). Fine roots (diameter ≤ 2 mm) are the primary pathway for water and nutrient uptake by plants and play a key role in the carbon dynamics of forest soils (Nadelhoffer et al. 1992; Trumbore and Gaudinski 2003). They appear to be extremely important in terms of the ecosystem NPP (Kalyn and Rees 2006; Chalermchatwilani et al. 2011) because of their short lifespan and high turnover rate (Joslin et al. 2006). If the dead fine roots are not decomposed, they will accumulate as root necromass in forest soils, trapping carbon in the forest ecosystem.

Information on fine root biomass and production are extraordinarily crucial and reasonably valuable for understanding ecological processes that ensue in mangroves (Adame et al. 2014), additionally, root production is associated with below ground carbon stocks and sequestration rates (Alongi 2011). Mangrove fine root production has rarely been investigated under natural forest conditions, whereas, coarse root can be estimated by using allometry equations (Clough 1992; Matsui 1998; Komiyama et al. 2005). Mangroves fine root production is prune to nutrient availability (McKee 2001; Feller et al. 2003; McKee et al. 2007; Adame 2014), when nutrients are limited, mangroves can allocate up to 60% of their biomass to root production and their productivity can be exceeded above ground productivity as fine root are constantly renewed (Komiyama et al. 2000; Helmisaari et al. 2002; Naido 2009). Mangroves root biomass and production also varies with interstitial salinity, though results are somehow conflicting (Krauss et al. 2013; Ball 1997; Ball 1998; Ball 2002), however, incrementing root production carried out the benefit to mangroves by booming water uptake in a saline condition that is believed (Ball 1988). Numerous methods have been established for quantifying fine roots in natural ecosystem (Osawa and Aizawa 2012) which comprises sequential core (Person 1980; Ostonen et al. 2005), ingrowth core (Finer et al. 1997; Ostonen et al. 2005), minirhizotron (Hendrick and Pregitzer 1993; Majdi and Ohrvik 2004), nitrogen budget (Nedelhoffer et al. 1985), and ecosystem carbon balance (Ågren et al. 1980). Recently, root scientists most often than not concur that simultaneous fine root growth and mortality cannot be estimated directly with soil core and ingrowth core method (Kurz and Kimmins 1987; Santantonio and Grace 1987; Majdi 1996; Majdi et al. 2005) that's why in this study soil sequential coring method was used for estimating fine root biomass.

The Sundarbans, the world's largest continuous patch of mangrove forest, is in the estuary of the river Ganges-Brahmaputra. The forest is distributed over two neighboring countries, Bangladesh and India. In Bangladesh, the forest covers 6,017 km^2 (21°30'-22°30' N, 89.00°-89°55' E). Chaffey et al. (1985) divided the Sundarbans mangrove forest into three ecological zones viz. fresh water (oligohaline), moderately saline water (mesohaline), and salt water (polyhaline) zones. Changes in salinity might be responsible for the spatial distribution of plant communities (Ahmed et al., 2011). There have been no previous studies found that examined the production of the fine root as well as stand structure in three salinity zone of Sundarbans Reserve Forest (SRF), Bangladesh with respect to its contribution and role in carbon sink in mangrove forest ecosystems in the tropics. In the present study, the structural characteristics, above ground biomass production as well as fine root contribution in carbon stock of the mangroves along the three different saline zones have been quantified with a view to comparing with it's belowground biomass and assessing their role in total carbon stocks of the SRF, Bangladesh.

Stand structure and the fine root of mangroves may be directly influenced the conditions and functioning of mangrove ecosystems, and its alteration may change distribution and abundance of their fauna (Cavalcanti *et al*. 2009; Kamruzzaman et al, 2018). Consequently, we hypothesized that dominant mangrove species have contributed more in biomass accumulation than other species. To test the hypothesis, we have assembled and analyzed data on specific species and fine root biomass, as well as carbon storage and compare with aboveground biomass production. Thus, the objectives of this study were to characterize, as the first step of our effort, the stand structure of mangrove forests along the three-saline zone of SRF and assessing their role in carbon storage. Species diversity, above and below-ground biomass carbon, and its relationship to different parameters such as tree's diameter class and species wise contribution were also examined and presented.

1.2 Objectives of the Study

Objectives of the present study were to:

- identify the contribution of fine roots in carbon stock of the mangrove communities
- detect the above ground carbon and below ground carbon of mangrove at different salinity zone
- Characterize the stand structure of mangrove at different saline zone

Stand characteristics, species density, and its relationship to different parameters such as height and diameter class were described. Patterns of species density vs. soil salinity were also examined and presented.

2.0 Literature Review

2.1 Forest Stand Structure

Forest stand structure is defined as "the physical and temporal distribution of trees in a stand" and include within the description of the distribution of species, vertical and horizontal spatial patterns, size of trees or tree parts, tree age, or combinations (Oliver and Larson, 1996; Kasawani et al., 2007). Descriptions of the forest stand structure are commonly based on the aggregation of individual plant measures such as density, tree diameter at breast height distribution. In addition to zonation, mangrove forests are also characterized by attributes such as species richness, canopy height, basal area, tree density, age or size class distribution, and understory development (Feller and Sitnik, 2002).

2.1.1 Diameter at Breast Height

One of the simplest forms of stand characterization is the measurement of tree diameter. Diameter is usually measured with a tape at 1.3m above ground level and this measurement is referred to as dbh. An important exception, however, concerns the mangroves with stilts-roots, such as *Rhizophora spp*, where the diameter measurement should be taken at 30 cm above. Diameter is closely related to standing development and can easily be converted to the basal area (Kasawani et al., 2007)

2.1.2 Tree height

The height is also a useful criterion in forest stand classification. In mangroves forest, stand height can be divided into three or four classes. Stand height at 0 – 9 m considered as regeneration while standing height at 10 – 19 m considered as a young stand. Lastly, when a standing height reaches at > 20 m, it considered as an old stand (FAO, 1994).

2.1.3 Basal area

Basal area is the space covered or area occupied by the stem of a tree. The basal area of a stand is the sum of the individual basal areas of all trees greater than a certain diameter per unit ground area. It is a good measure of the overall stand development and can be related to wood volume and biomass (UNESCO,1984)

2.2. Fine Root

Fine roots (diameter ≤ 2 mm) are the primary pathway for water and nutrient uptake by plants and play a key role in the carbon dynamics of forest soils (Trumbore and Gaudinski 2003). They appear to be extremely important in terms of the ecosystem NPP (Kalyn and Rees 2006; Chalermchatwilani et al. 2011) because of their short lifespan and high turnover rate (Joslin et al. 2006). If the dead fine roots are not decomposed, they will accumulate as root necromass in forest soils, trapping carbon in the forest ecosystem.

Fine roots of trees and understory vegetation play a significant role in the carbon and nutrients dynamics of forest soils, insufficient information available about their contribution to the carbon and nutrients budget (Gower et al. 1994; Bartelink 1998; Trumbore and Gaudinski 2003)

2.3 Relative Density

Relative density is the ratio of the density (mass of a unit volume) of a substance to the density of a given reference material. Specific gravity usually means relative density with respect to water. The term "relative density" is often preferred in scientific usage. It is defined as a ratio of the density of a substance with that of water.

If a substance's relative density is less than one, then it is less dense than the reference; if greater than 1 then it is denser than the reference. If the relative density is exactly 1 then the densities are equal; that is, equal volumes of the two substances have the same mass.

Relative density can be calculated directly by measuring the density of a sample and dividing it by the (known) density of the reference substance. The density of the sample is simply its mass divided by its volume (Schetz et al;1999)

Relative density (%) = (Total number of individuals of a species) / (All number of individuals of all species) × 100

2.4 Relative Frequency

Relative frequency is the frequency of a given species expressed as a percentage of the sum of frequency values for all species present

Relative frequency (%) = (number of trials that are successful)/ (total number of trials) × 100

2.5 Relative Dominance

Relative dominance is the basal area of a given species expressed as a percentage of the total basal area of all species present.

2.6 Important Value Index (IvI)

The sum of relative density, relative frequency, and relative dominance is termed as Important value Index and it lies between 0 and 300. IvI= (Relative density + Relative frequency +Relative dominance)

2.7 Effects of Salinity

The BSMF is divided into three subsystems almost in a north-south direction where salinity varies due to hydrological regimes

- The eastern subsystem is situated between Passur and Baleswar rivers and receives freshwater from the Ganges through Gorai-Madhumati (which holds little freshwater during the dry period) and lower Meghna. The subsystem is of low salinity (Oligohaline, <5%).
- The central subsystem is located west of Passur and east of Sipsa. The Passur relates to the Ganges through the Gorai River. However, the connection is blocked in the lean period by sandbars (chars). Due to reduced flow in the Ganges, the catchment area is extensively sedimented resulting in degradation of BSMF mainly due to increasing salinity (Mesohaline, 5% to <18%).
- The western subsystem is in the west of Sipsa river to the east of Raimangal-Harin Bhanga river along the border. The subsystem originated from several perennial water bodies (moribund delta). The Sipsa relates to Passur which is already with the low freshwater flow.

Thus, the system does not receive any surface water from upstream during the dry period except local runoff. Seawater intrudes making the subsystem saline (Polyhaline, 18% to 30%). In the northern part (eastern and central subsystem) of BSMF, water salinity varies from 4% to 28%in April and May, while in the post-monsoon it is 1% to 9% (Siddiqi, 1992). In a period of eight months (from September to May), water salinity increased three to eight-fold, while the soil salinity increased two to five-fold (Karim, 1994; Aziz and Paul, 2015).

3.0 Materials and methods

3.1 Study Site

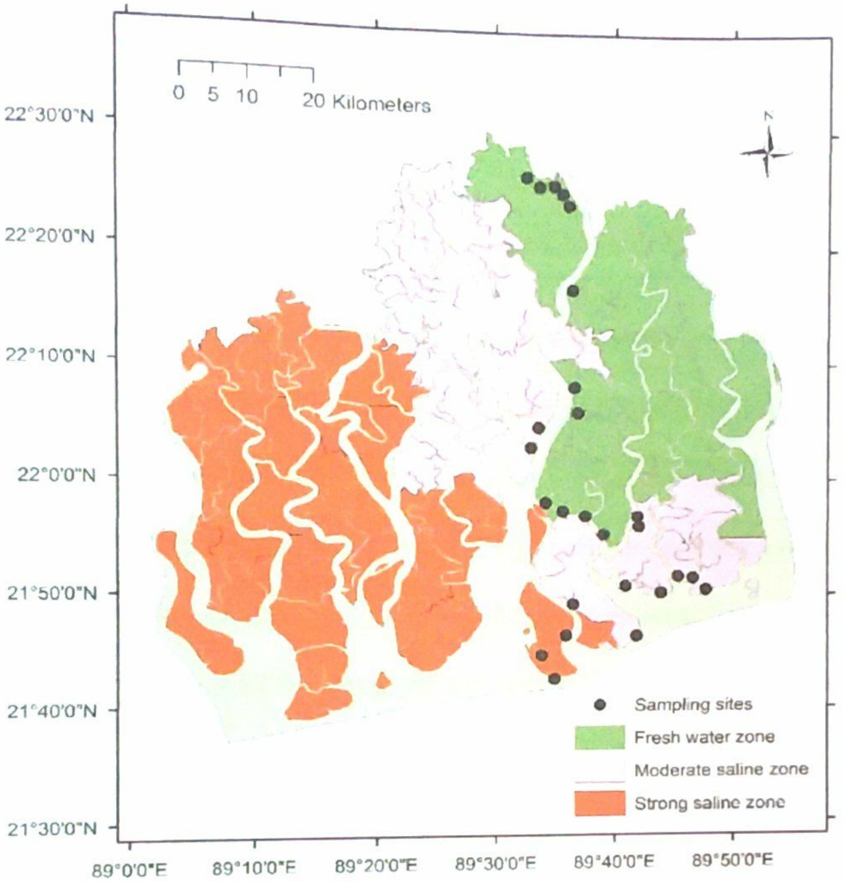
The Sundarbans forest in Bangladesh part is at 21°38′10.18″ and 22°29′51.65″ N and 89°02′22.87″ and 89°53′13.93″ E from Harinbhanga River to the west of Baleswar river in the east. The forestland surface is flat and ground elevation is about 0.9 to 2.11 m above the mean sea level (Khan 2011; Aziz and Paul 2015)

This forest is situated in the warm, humid tropical region where the mean annual minimum and maximum temperatures are 21 and 30 °C, respectively, mean annual relative humidity varies from 70% to 80% and annual rainfall differs from 1640 and 2000 mm (Aziz and Paul 2015).

My study was conducted in three saline zones like as three ecological zones viz. fresh water (oligohaline), moderately saline water (mesohaline), and salt water (polyhaline) zones areas of Sundarbans Reserve Forest (SRF) These areas receive regular tidal inundation through the Rivers of Passur and Shela.

We established ten (20 m × 20 m) plots and seventeen (10 m ×10 m) plots in three saline zones, among these, Oligohaline, Mesohaline, and Polyhaline zones covered 2100 m^2, 1900 m^2 and 1700 m^2 respectively. The pictorial presentation is given in my study area in Fig. 1.

Fig 1. Showing the location of sampling sites, in Sundarbans, Bangladesh.



The size of the plots differed between salinity zones due to the differences in size and density of the mature trees and seedlings along with the chance of accessibility. Where all the plots were considered roughly 200 m apart from the shore because of the destruction of the plot due to river erosion and damages due to storms. Moreover, for estimating fine roots, a Soil sample was taken within the plots.

3.2 Forest Structure

Species composition, tree density, and basal area were quantified through measurements of species, diameter at breast height (1.3 m) and height of all trees rooted within each plot which larger than 1.8 cm in diameter at breast height (*DBH*), as structural characteristics (dbh and height) of the mangrove stands are the primary determinants of carbon storage (Cintron and Schaeffer Novelli 1984). Forest density (trees ha^{-1}) was extrapolated according to plot size as well as salinity zone.

3.3 Above and Below Ground Biomass as well as Carbon Estimation

Although allometric relationships have been developed between dbh and weight for several mangrove species around the world, biomass production relies on the interaction between edaphic, climatic and topographic factors of the specified area and the species that occurred on the specific area. Unfortunately, there is no developed allometric equation for biomass estimation of the studied mangrove species encountered in this study. So, we cautiously apply the following aboveground biomass equation for all the mangrove tree species (Chave *et al.* 2005).

$$AGB = 0.0509 \text{ x } \rho \text{ x } D^2 \text{ x } H$$

where AGB = aboveground biomass, ρ = wood density, D = dbh. and H= height. The wood density data were obtained from Globathe l Wood Density Database (Chave *et al.* 2009).

Below-ground biomass of mangrove tree species was estimated using common allometric relationships between dbh and biomass, established by Komiyama *et al.* (2005).

$$BGB = (0.199\,.\ \rho^{0.899} D^{2.22})$$

where BGB= belowground biomass, ρ = wood density, D = dbh. Individual tree's biomass calculation for each species was estimated using the same allometric equation. The common allometric relationship for root weight was derived from the relationship between the below-ground and above-ground weight of trees, so wood density is the same for both above-ground and below-ground weight estimation. Conversion of the biomass of trees to carbon mass was done by multiplying forest biomass by 0.5 as carbon concentration is regularly 50% (Gifford 2000; Kauffman and Donato 2012).

3.4 Fine Roots Biomass and carbon estimation

Four cores were taken randomly within each plot with a stainless-steel corer and the cores were – cm in diameter and 30 cm depth which was divided into 10cm each that illustrate Upper (0-10 cm), Middle (10-20 cm) and Lower (20-30cm) sequentially. In total, 80 cores were taken, however, twenty from oligohaline, twenty-eight from mesohaline, and further thirty-two from polyhaline salinity zones plot. Each core was kept in a cold and dry place, on top of that, it was taken to the laboratory, in where, it was rinsed with fresh water through 2 mm, 1 mm, and .25 mm sieving mesh simultaneously, moreover, which were separated then into three fractions: 1-2 mm, .5-1 mm and 0-.5 mm sequentially diameter class and weighed before and after being oven dried at 60 °C (Castaneda-Moya et al. 2011). By following this technique, we measured the biomass of fine roots with a maximum diameter of 2 mm from the shallow root zone (0-30 cm), which is the largest and most active portion of the roots (Castaneda-Moya et al. 2011). Fine root biomass in different salinity zones is shown as megagrams per hectare (Mgha^{-1}) which was converted into biomass carbon by following Gifford (2000), later.

3.5 Statistical Analysis

A two-way analysis of variance (ANOVA) was used to determine significant differences for fine root biomass among saline zone and depths (0-10 cm, 10-20 cm, 20-30 cm) in where fine root biomass was considered as a dependent variable, salinity and depths were thought as independent variables. When significant found, pairwise comparisons were explored using Bonferroni posthoc tests. Tukey test was performed to test the relationship between root biomass/ production with salinity. For all statistical analyses, we used a significance value of $\alpha < 0.05$. throughout the results, all values are shown as mean ± standard error. All the statistical analyses were performed using SPSS version 16 and Microsoft Excel 2013 software (Microsoft, Redmond, WA, USA). Figures were drawn using Kaleida Graph v 4.1 (Synergy software, USA) and R version 3.1.0 (R Core Team 2014).

4.0 Results

4.1 Stand structure

Structural composition of mangrove communities along the Oligohaline, Mesohaline, and Ployhaline zones of Sundarbans Reserve Forests (SRF) and their structural composition are presented in Table 1.

Table 1. The structural composition of mangrove communities within three saline zones of Sundarbans, Bangladesh.

Salinity Zone	Species	Specific density (n ha^{-1})	Basal area (m^2 ha^{-1})	Relative density (%)	Relative frequency (%)	Relative dominance (%)	Importance value I_v
Oligohaline	AGCU	25	0.1	0.8	7.5	0.3	8.5
	AVOF	95.8	7.3	6.3	11.7	23.6	41.5
	BRSE	150	2.6	6.2	10.8	11.2	28.3
	CMAN	8.3	0.0	0.3	4.2	0.1	4.6
	EXAG	791.7	3.8	24.9	24.7	9.0	69.7
	HEFO	1395.8	8.9	49.5	24.7	33.9	110.1
	XYME	212.5	2.6	12.1	16.4	8.0	37.2
Mesohaline	AVOF	120	2.38	4.5	5.8	6.6	17.0
	BRSE	10	0.40	0.9	2.5	1.0	4.3
	CEDE	220	0.82	8.5	15	3.8	27.2
	EXAG	1120	15.62	40.4	35	51.1	126.5
	HEFO	1095	11.00	36.2	26.7	31.0	93.9
	XYME	120	1.51	9.5	15	6.6	31.1
Polyhaline	AGCU	9.1	0.1	0.5	2.3	0.1	2.9
	AVAL	4.5	0.1	0.8	3.0	0.4	4.2
	AVOF	11.4	1.8	0.9	6.1	4.6	11.6
	CEDE	261.4	1.2	15.0	14.4	8.6	38.0
	EXAG	936.4	10.6	48.8	31.1	42.0	121.9
	HEFO	261.4	3.5	15.2	22.0	13.1	50.2
	SOAP	97.7	19.8	17.9	16.7	27.9	62.5
	XYME	18.2	0.9	0.8	4.5	3.2	8.6

Here, AGCU= *Aglaia cucullata*, AVAL= *Avicennia alba*, AVOF= *Avicennia officinalis*, BRSE= *Bruguiera sexangula*, CEDE= *Ceriops decandra*, CMAN=*Cerbera mangas*, EXAG= *Excoecaria agallocha*, HEFO= *Heritiera fomes*, SOAP= *Sonneratia apetala*, XYME= *Xylocarpus mekongensis*.

In the oligohaline zone, the preponderance of *H. fomes* gives it a high importance value index (Iv = 110.1), moreover, the Iv for *A. cucullata*, *A. officinalis*, *B. sexangular*, *C. mangas*, *E. agallocha*, and *X. mekongenis* were 8.5, 41.5, 28.3, 4.6, 69.7 and 37.2 respectively. Meanwhile, the I_v of *E. agallocha* clicked the zenith position in both the mesohaline and polyhaline zone. In the mesohaline zone, B. sexangula hold the lower most IV value only 4.3, whereas, *A. officinalis*, *C. decandra H. fomes and X. mekongensis* carried 17.0, 27.2, 93.9, and 31.1 correspondingly. In addition, *A. cucullata* and *A. alba and X. mekongensis* switched the three lowermost Iv value that were 2.9, 4.2 and 8.6 individually. On top of that, the Iv value of *A. officinalis*, *C. decandra*, *H. fomes*, *S apetala, and X. mekongensis* were 11.6, 38.0, 50.2, 62.5 and 8.6 sequentially.

The specific density and relative dominance of *H. fomes* in the oligohaline zone area were 1396 ha^{-1} and 33.9%, respectively. Based on the species Iv, *H. fomes* was the principle species in the mangrove community along the oligohaline zone of Sundarbans. Similarly, the specific density and relative dominance of *E. agallocha* in the mesohaline and polyhaline zone area were1120 ha^{-1} and 937 ha^{-1}, relative dominance was 51.1% and 42%, respectively. So, *E. agallocha* was the key species in both mesohaline and oligohaline based on Iv. Similarly, because of relative dominance, *A. officinalis* and *H. fomes* were considered for carbon stock estimation in their respective above-ground structures in the oligohaline zone. On the same way, *H. fomes* in mesohaline and *S. apetala* in the polyhaline zone are considered for carbon stock estimation with the *E. agallocha* as it key species in these zones. Structural features of the mangrove community along the three saline zones are presented in Table 2.

Table 2. Stand structure of mangrove communities within three saline zones of Sundarbans, Bangladesh.

Salinity zone	Density (n ha^{-1})	Total basal area (m^2 ha^{-1})	Mean H (m)	Mean DBH (cm)
Oligohaline	2679.2±182.2	25.3	9.6±.6	11.4±.92
Mesohaline	2685±192.2	82.4	11.3±.6	18.5±1.4
Polyhaline	1600±104.8	37.9	11.3±1.2	19.0±3.4
Mean	2321.4±159.7	48.5±2	10.7±.8	16.3±1.9

4.2 Biomass and carbon accumulation in both above and below ground

The mean above-ground biomass of the mangrove stands was 232.0±65.8 Mg ha^{-1}. The total above-ground biomass ranged from 189.6 Mg ha^{-1} in the oligohaline zone to 286.2 Mg ha^{-1} in polyhaline zone. Further, the mean belowground biomass of the studied stands was 142.2 ±31.0 Mg ha^{-1}. The total below-ground biomass ranged from 92.0 Mg ha^{-1} in the oligohaline zone to 187.2 Mg ha^{-1}. Mean above-ground, below-ground, and total biomass carbon (TBC) of the three saline zone areas were 116.0 ± 32.9, 71.1 ± 15.5, and 187.1 ± 48.4 Mg ha^{-1} respectively (Table 3). The TBC stock was highest in polyhaline zone area of Sundarbans mangrove forest.

Table 3. Carbon accumulation (Mg ha^{-1}) in mangrove communities within three saline zones of Sundarbans, Bangladesh.

Salinity zone	Aboveground Biomass Carbon (Mg ha^{-1})	Belowground Biomass Carbon (Mg ha^{-1})	Total Biomass Carbon (Mg ha^{-1})
Oligohaline	94.8±24.6	46.0±6.7	140.8±31.3
Mesohaline	110.1±27.1	73.7±14.0	183.8±41.1
Polyhaline	143.1±47.0	93.6±25.7	236.7±72.8
Mean	116.0±32.9	71.1±15.5	187.1±48.4

To explore the contributions of species in carbon stocking, we calculated the species-wise carbon contents in Figure 2a. Figure 2b, and Figure 2c.

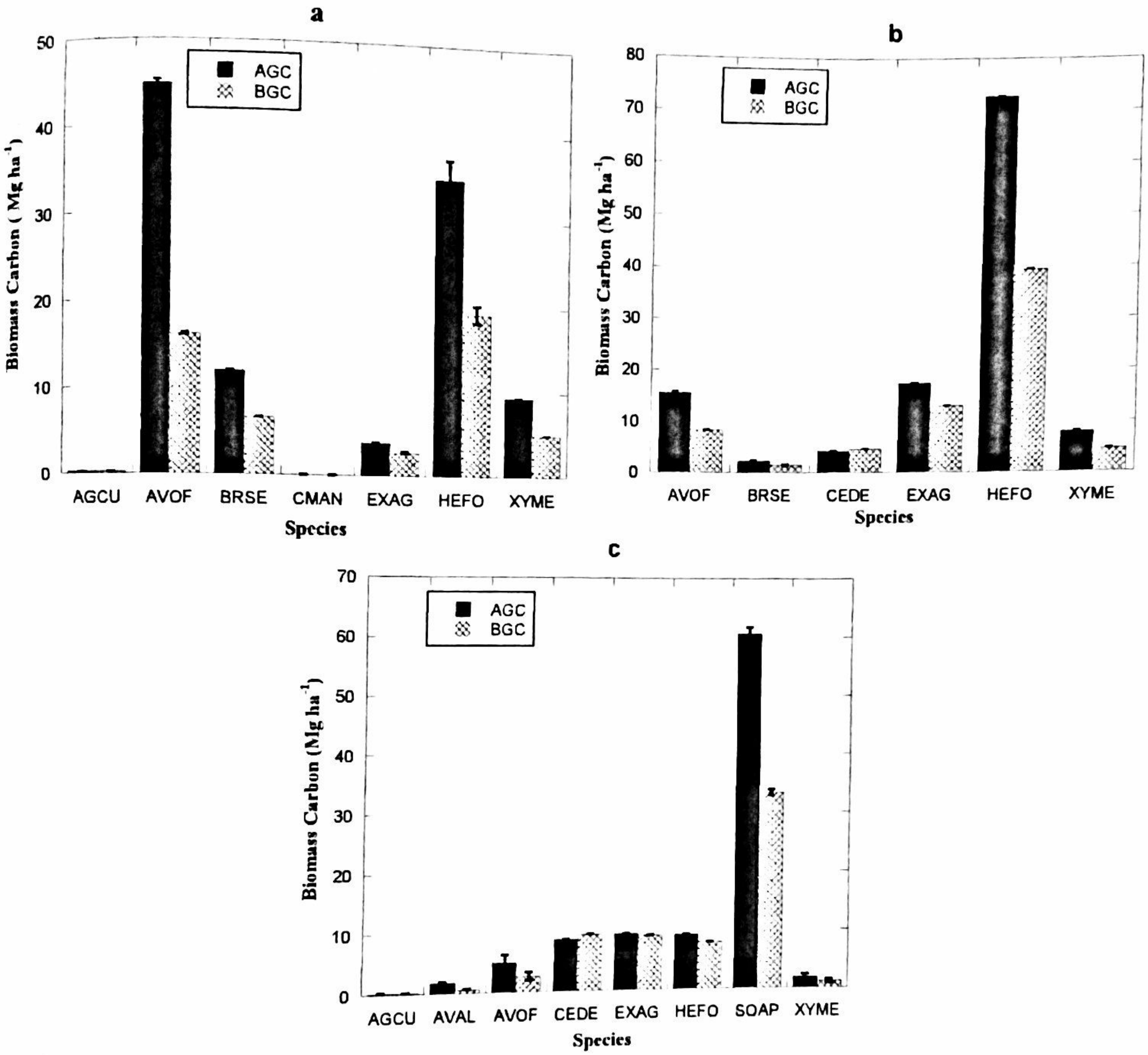


Fig. 2: Species wise contribution to biomass carbon stocks (AGC= above-ground biomass carbon; BGC= below-ground biomass carbon). **a** oligohaline zone; **b** mesohaline zone area; **c** polyhaline zone.

(AGCU: *A. cucullata*, AVAL: *A. alba*, AVOF: *A. officinalis*, BRSE: *B. sexangula*, CEDE: *C. decade*, CMAN: *C. mangas*, EXAG: *E. agallocha*, HEFO: *H. fomes*, SOAP: *S. apetala*, XYME: *X. mekongensis*.)

In both oligohaline and mesohaline zone, *H. fomes* contributes the key amount carbon in carbon stocks, whereas, in polyhaline zone, *S. apetala* stayed in the mountain for reinforcing the carbon stock. Moreover, *A. officnalis* and *B. sexangular* surged the carbon storage in oligohaline zone as well.

In the oligohaline zone, the order of species wise carbon stock in the TBC including above-ground and below-ground biomass carbon *was H. fomes > A. officinalis >B. sexangula > X. mekongensis >E. agallocha >A. cucullata> C. mangas. H. fomes* contributed the most to the TBC, while A. officinalis was the second highest contributor of carbon accumulation in the oligohaline zone. Notably, A. officinalis constituted lower amount in the total number of individuals but contributed almost same as *H. fomes* to the TBC. This is due to very large *A. officinalis* trees were found at scattered locations throughout the oligohaline zone.

Number of individuals that contributed to their respective portions of species wise carbon stocking in the Mesohaline zone area was *H. fomes >E. agallocha >A. officinalis > X. mekongensis > C. decandra > B. sexangula.* On the other hand, individual species contributions in carbon pool in the polyhanie zone area was *S. apetala >E. agallocha > H. fomes >C. decandra > A. officinalis> X. mekongensis >A. alba >A. cucullata.* In this study area, *S. apetala* dominantly contributes biomass carbon in the carbon storage.

4.3 Fine Root Biomass Carbon Estimation

Fine root biomass carbon ranged from 13.3 $Mgha^{-1}$ in the polyhaline zone to 23.3 $Mgha^{-1}$ in the oligohaline zone. In addition to, mean fine root biomass carbon (FRBC) packed 16.9 ± 2.0 $Mgha^{-1}$ in Sundarbans, Bangladesh. Zone wise fine root contribution in the carbon stock presented in table 4. and Fig.3

Table 4. Fine root biomass (Mg ha^{-1}) in different saline zones and at several depths

Salinity zone	Depth (cm)	FRBS(Mgh^{-1})
Oligohaline	10	17.0±2.1
	20	17.1±2.8
	30	12.6±1.7
Mesohaline	10	10.3±1.4
	20	9.3±0.71
	30	8.6±0.7
Polyhaline	10	9.0±0.9
	20	9.1±1.0
	30	8.6±0.9
Mean		33.84±4.0

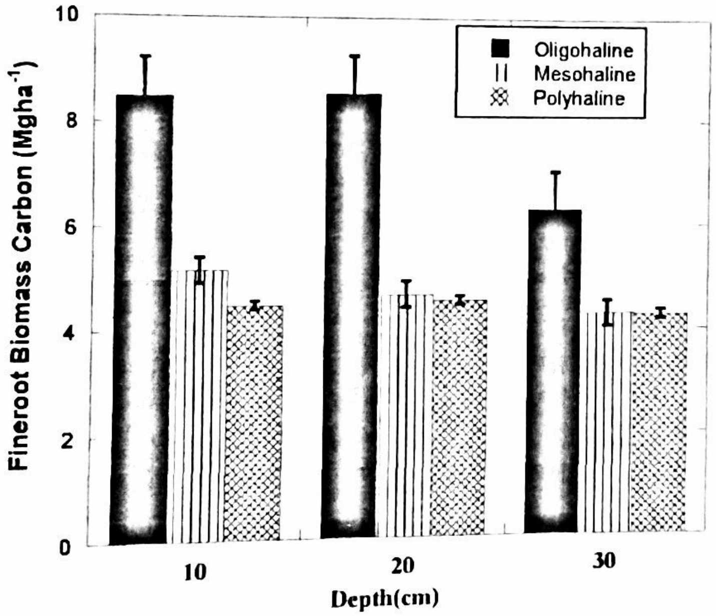


Fig.3 Illustrating the Fine root biomass carbon along the salinity zone at different soil depth.

Oligohaline zone is significantly different from polyhaline and mesohaline zone for contributing fine root in carbon pool (P<0.05). On the other hand, there is no significant difference found between polyhaline and mesohaline (P>0.05), which is presented in Table 5.

In stark contrast, there is no significant dissimilarity observed between soil depth with relevant to fine root biomass production.

Table 5. Illustrating significant different between three saline zones and soil depth

Source	df	Mean Square	F	Sig.
Saline Zone	2	935.474	20.191	.000
Depth	2	107.571	2.322	.100
Saline Zone * Depth	4	36.232	.782	.538
Error	231	46.331		
Total	240			

In the oligohaline zone, overall, fine root contribution based on diameter dramatically illustrating higher than polyhaline and mesohaline. Fig 4. Presenting the fine root contribution based on diameter in the individual zone, associating with soil depth.

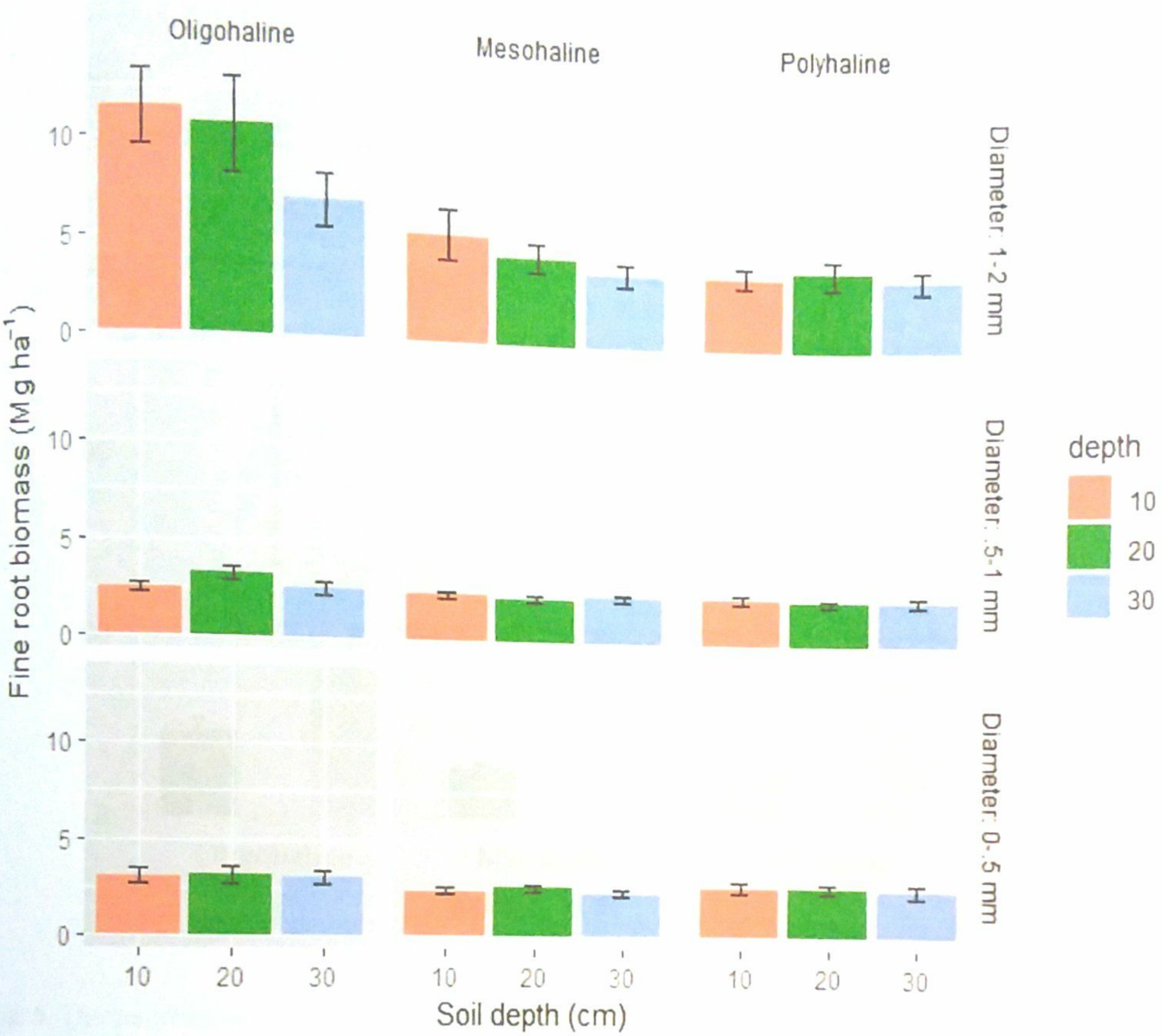


Fig.4 Fine root biomass and its contribution in three saline zones based on diameter class and depth

Overall, fine root contributing almost one-third of the belowground biomass carbon that is considered roughly half than aboveground biomass that is shown in Fig. 5.

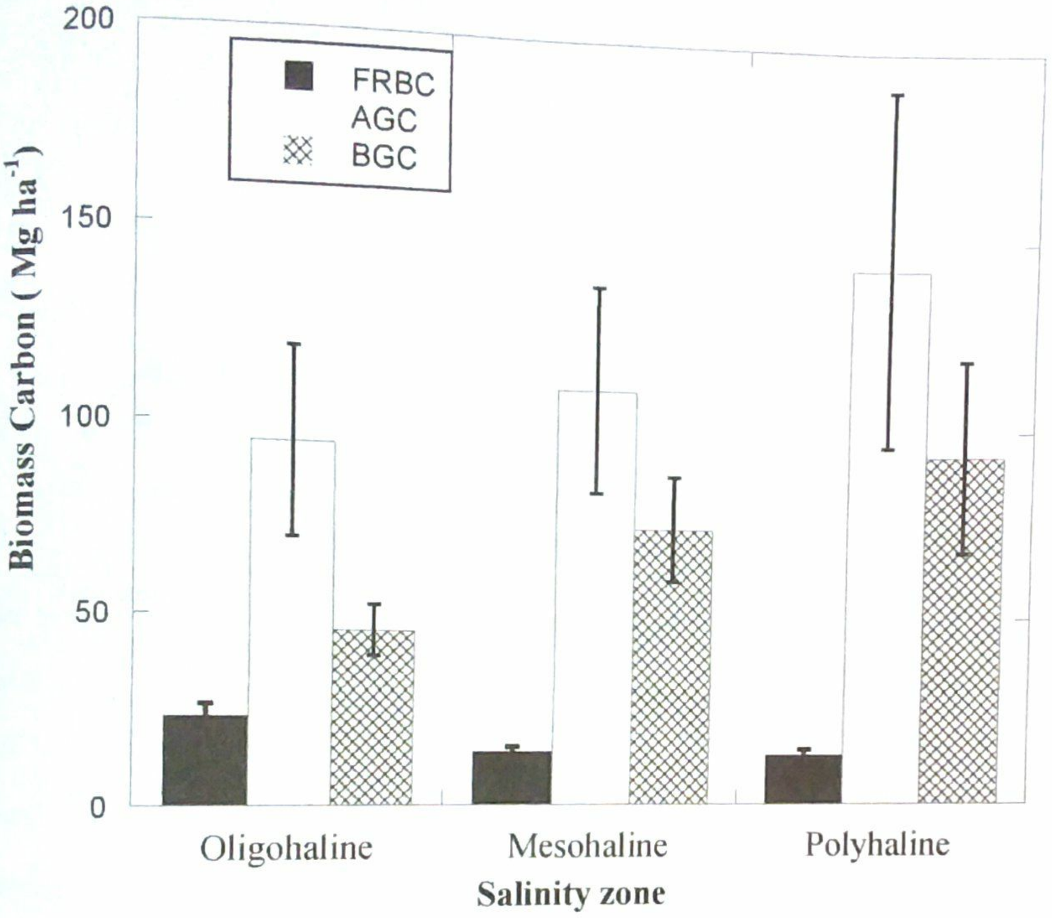


Fig. 5. The contribution of fine root biomass carbon (FRBC), AGC and BGC in different salinity zone in Sundarbans, Bangladesh.

FRB is significantly correlated with stand density and basal area (Fig. 6). Accumulation of fine root biomass elevated by booming the stand density and basal area of the stands. Further, fine root biomass dramatically relevant with above and below ground biomass also.

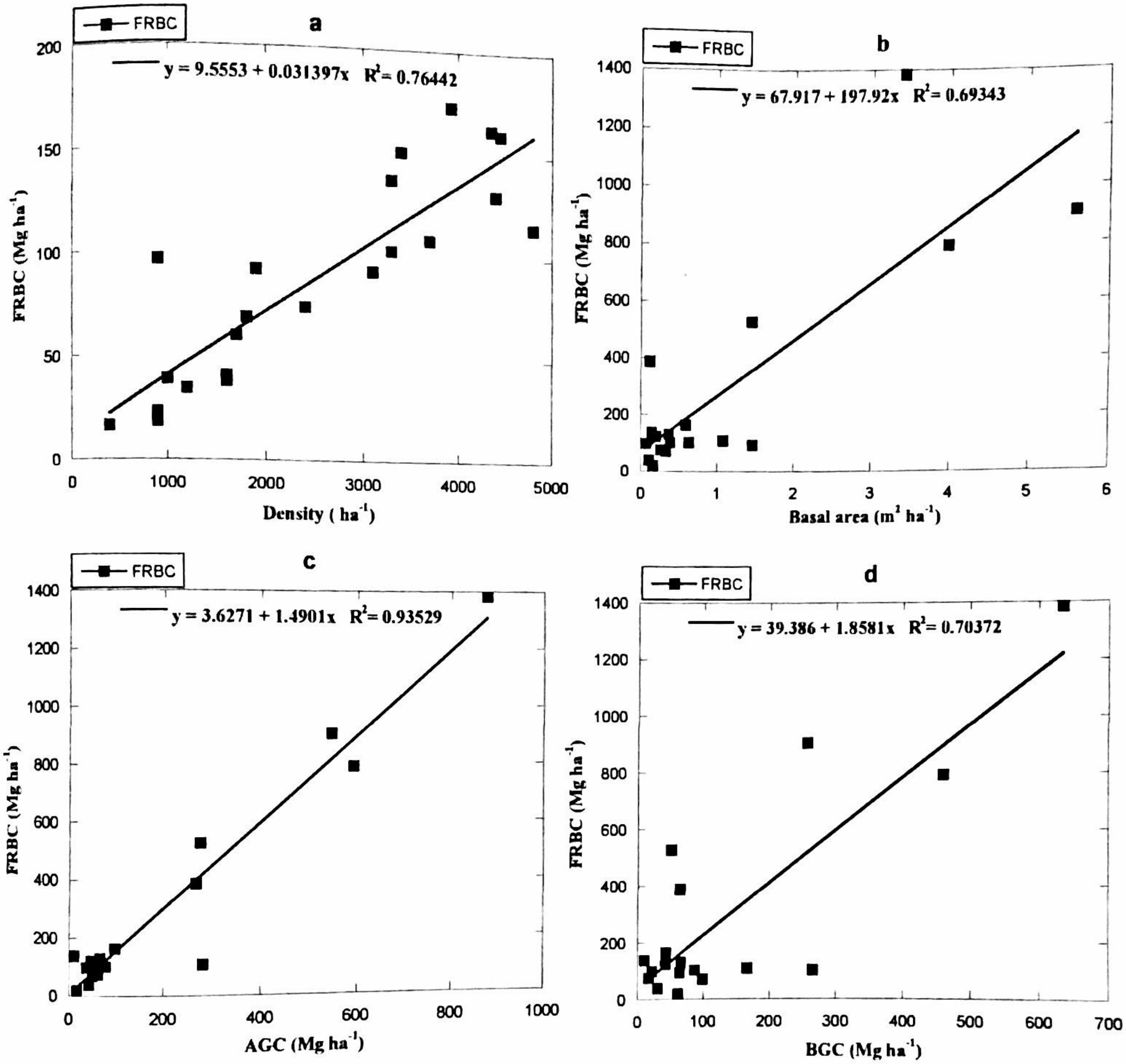


Fig.6.Showing the relationship between FRBC (fine root biomass carbon) **a.** stem density (ha^{-1}) **b.** basal area (m^2 ha^{-1}) **c.** AGC (Above ground biomass carbon) and **d.** BGC (Below ground biomass carbon)

5.0 Discussion

5.1 Stand structure

Stand density in three salinity zones in Sundarbans Bangladesh ranged from 1600 ha^{-1} in polyhaline zone to 2685 ha^{-1} in mesohaline zone are comparatively lower than mature riverine mangrove forests or mixed mangrove stands (3310-917 ha^{-1}) in French Guiana that was claimed by Fromard et al. (1998), where they found much more density at the pioneer stage rather than mature stands. However, our study signified higher densities in three salinity zones than Haron (1981) and Aksornkoae (1993) who presented mean density of mature mangrove stand of 1343stems ha^{-1} in Matang mangrove, Malaysia and 812 stems ha^{-1}, Ranong, Indonesia. In our current study, a community with small stands had higher density like oligohaline zone and mesohaline zone rather than a community with large trees had shown less density (Table 2). These results designate competition for resources within the stands, which invents size variation and density-depended mortality, or sometimes self-thinning might happen. Kamara et al. (2014) claimed density depended mortality or self-thinning is a natural prodigy in packed mangrove stands on Okinawa Island, Japan, meanwhile, our investigations concur with this statement. On top of that, our study also supports the Fromard et al. (1998) declaration who evokes that density was the most discriminating factor for the young development stage of mangroves, where, a young stand matures by eliminating the number of individuals.

Seven, six and eight mangroves were found in oligohaline, mesohaline and polyhaline zones sequentially in our study area. *Heritiers fomes, Exocaria agallocha* had occupied dominancy in the oligohaline and mesohaline zone and had the highest importance value (I_v=110.1, and 126.5 in sequence) among the all other species in these two zones. Reversely, *Exocaria agallocha* and

Heritiers fomes were the second most leading species in the following zones who occupied 69.7 and 93.9 I_v value successively. Similarly, in the polyhaline zone, *Exocaria agallocha* and *Sonneratia apetala* were the key individuals (I_v= 121.9 and 62.5 consequently). *Exocaria agallocha* and *Heritiers fomes* had upheld the advanced importance value than that of the dominant mangrove species of the Andaman Islands, India (88.4 and 48.7, respectively) that was claimed by Padalia et al. (2004). The Iv value for ruling species was also higher than that reported for the dominant species (I_v= 69.3~61.1) in mangroves of the northwestern coast of Srilanka (Perera et al. 2013). The findings of the present study disclose that mangrove forest along the three salinity zones is miscellaneous in species composition, and abundance, as it exposed by various indicators of diversity.

5.2 Biomass and carbon accumulation in both above and below ground

The present study demonstrated that the mean above ground biomass (233.3 Mg ha^{-1}) was much higher than that a subtropical mangrove forest on Ishigaki Island, southern Japan (97.6 Mg ha^{-1}) which was claimed by Suzuki and Tagawa (1983), *Avicennia marina* (Forssk.) Vierh dominated mangrove Sofala Bay, Mozambique (134.6 Mg ha^{-1}) reported by Sitoe et al. (2014) and at Florida, the USA the fringe mangrove forest which was dominated by *R. mangle* showed 26.1 Mg ha^{-1} (Ross et al. 2001). This value is also higher than the mean value of above ground biomass (89.7-42.9 Mg ha^{-1}) for *B. parbiflora*, (76.0-279.0 Mg Mg ha^{-1}) for *B. sexangular*, and (40.7 Mg ha^{-1}) for R. apiculata dominated mangrove forest in East Sumatra, Indonesia claimed by Kusmana et al. 1992. The present above ground biomass value was lower than above ground biomass value of a mature *Rhizophora- Bruguiera* dominated mangrove forest in Malaysia (270~460 Mg ha^{-1}; Putz and Chan 1986). It is also advanced than *R. apiculata* dominated mangrove forest (159 Mg ha^{-1}) in southern Thailand (Cristensen 1978). Comparing with the previous study it indicates that biomass productivity of the mangroves among the three saline zones is relatively high rather than tropical and subtropical mangrove forest areas.

Accumulation of mean aboveground biomass carbon of the studied area was 116.64 Mg ha^{-1} which was higher than 92.1 Mg ha^{-1} that was observed by Komiyama et. al (2000) in a secondary mangrove forest in southern Thailand. The range of the above-ground biomass carbon among the three saline zones were 84.97 Mg ha^{-1} to 135.87 Mg ha^{-1} superior than mangrove forest of Sundarbans, India that was 22.1- 111.4 Mg ha^{-1} (Mitra et al. 2011) and 34.6- 90.8 Mg ha^{-1} which was presented by Ray et al. (2011).

The presented above ground biomass carbon mean value including the three saline zones was higher than mangroves in Micronesia (104.4 Mg ha^{-1}; Kauffman et al. 2011). Among the three saline zones mean biomass carbon accumulation 180.43 Mg ha^{-1} was significantly higher than Sofala Bay, Mozambique mangroves 58.6 Mg ha^{-1} (Sitoe et al. 2014), in China 84.6 Mg ha^{-1} (Liu et al. 2014), and Yunguluo Bay, Guangdong province in South China 86 Mg ha^{-1} (Wang et al. 2013). Tree biomass carbon both above and below ground among the zones was highly variable in the present study (Table 3). It is interesting to note that carbon storage in the mesohaline zone was much lower than the polyhaline zone where the stem density was much higher than polyhaline zone.

This is the very first study to depict the fine root and species wise biomass; it's contributions to the Sundarbans among the different salinity zones.

5.3 Fine Root Biomass and Carbon Estimation

Root biomass was clearly manipulated by forest structure, with the highest values measured in the oligohaline zone in where density and basal area of the species were higher as well as salinity was lower than polyhaline and mesohaline zone, density increases ultimately competition increases which forces to produce fine root to acquire limited resources, our study (Table 3 and Fig 3) support the statement (Komiyama et al. 1987; Lopez et al. 1998). The mean FRB 33.84 Mg ha^{-1} was much higher than Knasaa tall grass prairie live and dead fine root varied from 6~11.8 Mg ha-1(Hayes and Seastedt 1987). Our current FRB value was higher than a multispecies riparian buffer in Central Iowa, the USA which was ranged from 5.8~17.0 Mg ha^{-1}. Total fine root biomass in boreal, tropical evergreen and tropical deciduous forest were 6.0 Mg ha^{-1}, 5.7 Mg ha^{-1}, and 5.7 Mg ha^{-1}respectively claimed by Jackson et al. (1997) was lower than our current study. The presented mean (33.84±4.0 Mg ha^{-1}) FRB was also advanced than boreal (5.26 ± 3.21 Mg ha^{-1}), temperate (7.75 ± 4.74 Mg ha^{-1}) and tropical forests (7.76 ± 5.18 Mg ha^{-1}) (Finer et al. 2011). Accumulation of mean fine root biomass carbon 16.9 Mgha-1 was superior to FRB 11.3 Mg ha^{-1}of mangrove forest in Okinawa, Japan (Nishino 2010). The present study demonstrated that the mean value of FRB (33.84±4.0 Mg ha^{-1}) in Sundarbans, Bangladesh is much higher than mangroves surrounding a Karstic Oligotrophic Coastal Lagoon (17.06± 6.69 Mg ha^{-1}, Adame et al. 2014).

6.0 Conclusion

To recapitulate, biomass and carbon storage may be swayed by species diversity and size classes rather than dominance. On the other hand, fine root biomass was not significantly related to depth, in contrast, dramatically affected by salinity. Additionally, 2 mm diameter class fine root estimated handsome amount rather than the other two diameter class fine root. Finally, it may be concluded by saying that fine root had immense importance not only for nutrient up taking but also in global carbon budget.

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